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Technical Report Number 25

THE HAULING-OUT BEHAVIOR OF THE PACIFIC WALRUS

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By

Douglas Wartzok & G. Carleton Ray

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Important questions on the natural history of marine mammals need to be answered before management can be placed on a more certain basis. We investigated one aspect of the natural history of Pacific walruses, Odobenus rosmarus divergens. We concentrated on walrus hauling-out behavior and the associated environmental factors which influence this behavior. We employed primarily visual photography and infrared imaging in order to gain new insights into the relationship between behavior and the environment.

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for distinguishing walruses from their haulout areas and for counting the ani-
mals. Infrared imaging was much better for detecting small groups of animals,
particularly when the ice was broken up into many small floes. Most remote
sensing flights were conducted at an altitude of 300 to 400 m since this alti-
tude gave the best resolution for counting animals on the photographs.

In a discriminant analysis with the discriminant variables being 4 cate-
gories of ice thickness of April 1976 winter ice, we were able to show good
discrimination between three types of areas: those containing less than 2%,
2 to 10% and greater than 10% of the observed hauled-out walruses. However,
when the discriminant functions derived from April 1976 data were applied to
April 1975 data, predicted walrus distribution from habitat classification
based on ice thickness did not accord with the actual distribution of walruses.

In the late summer, August 1975 and September 1974, the walrus hauled out
predominantly on floes with areas of 50 to 400 m^2 although floes of these sizes
made up a small fraction of the total floe sizes available.

Both the late winter and late summer distribution of walrus group sizes
can be fit with a truncated negative binomial distribution. The "aggregation
parameter" of this distribution, 1/k, is larger for walrus groups in the late
winter than in the late summer.

We conclude that the data return from any walrus survey can be significant-
ly improved by using new methods which employ synoptic data gathering through
remote sensing. We emphasize the necessity of additional remote sensing and
radio tracking studies to develop the walrus hauling-out model ideas we pre-
sent into a predictive model. We also recommend consideration of the tech-
niques used here for other marine mammal species.

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The Hauling-Out Behavior of the Pacific Walrus

Douglas Wartzok, G. Carleton Ray

Marine Mammal Commission
Washington, D. C.

April 1980

Report No. MMC-75/15

THE HAULING-OUT BEHAVIOR OF THE PACIFIC WALRUS

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16. Abstract

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ABSTRACT

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High-resolution color film proved to be the best remote sensing technique for distinguishing walruses from their haulout areas and for counting the animals. Infrared imaging was much better for detecting small groups of animals, particularly when the ice was broken up into many small floes. Most remote sensing flights were conducted at an altitude of 300 to 400 m since this altitude gave the best resolution for counting animals on the photographs.

In a discriminant analysis with the discriminant variables being 4 categories of ice thickness of April 1976 winter ice, we were able to show good discrimination between three types of areas: those containing less than 2%, 2 to 10% and greater than 10% of the observed hauled-out walruses. However, when the discriminant functions derived from April 1976 data were applied to April 1975 data, predicted walrus distribution from habitat classification based on ice thickness did not accord with the actual distribution of walruses.

In the late summer, August 1975 and September 1974, the walrus hauled out predominantly on floes with areas of 50 to 400 m^2 although floes of these sizes made up a small fraction of the total floe sizes available.

Both the late winter and late summer distribution of walrus group sizes can be fit with a truncated negative binomial distribution. The "aggregation parameter" of this distribution, $1/k$, is larger for walrus groups in the late winter than in the late summer.

We conclude that the data return from any walrus survey can be significantly improved by using new methods which employ synoptic data gathering through remote sensing. We emphasize the necessity of additional remote sensing and radio tracking studies to develop the walrus hauling-out model ideas we present into a predictive model. We also recommend consideration of the techniques used here for other marine mammal species.

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To count is a modern practice, the
ancient method was to guess; and when
numbers are guessed they are always
magnified.

> Samuel Johnson
>
> A Journey to the
> Western Islands
> of Scotland

INTRODUCTION

Many important questions regarding the management of marine mammal populations cannot be answered because of a lack of information on population identity and home range, on the number of individuals in each population, and on the natural history of the animals. This paper is primarily: (1) an exploration of how remote sensing techniques can contribute to an understanding of the natural history of the Pacific walrus, Odobenus rosmarus divergens, with particular emphasis on its hauling-out behavior; and (2) a discussion of how this information can contribute to walrus management programs.

We have used several remote sensing techniques and have obtained "ground truth" data from icebreakers, native boats, and sea ice with walruses in order to meet the stated objectives of this contract. These objectives were to:

1. determine hauling-out patterns of the Pacific walrus (Odobenus rosmarus divergens) in relation to meteorological, temporal, and sea ice conditions;

2. investigate the behavioral and physiological thermoregulatory aspects of hauling out; and

3. model the data obtained in such a manner that they may be incorporated into assessment programs.

The specific tasks required which generated the data on which this report is based were to:

1. observe and remotely sense walruses to determine hauling-out patterns in relation to meteorological, temporal, and sea ice conditions;

2. conduct field studies and utilize remote sensing to study the behavioral and physiological thermoregulatory aspects of hauling out; and

3. develop, utilizing the above data, a preliminary predictive model for hauling-out behavior of the Pacific walrus for incorporation into assessment programs to yield greater precision during censuses.

Our knowledge of the natural history of marine mammals is limited by our ability to observe them. Thus we know most about those aspects which can be observed when the animals are at the surface of the water or when they are hauled out. Remote sensing does not break through this major constraint, but it does allow us to maximize the data obtained when the animals are observable since it provides population and environmental information in a format which can be studied and reevaluated as necessary. Enhanced knowledge of the factors influencing hauling out has direct management implications.

The walrus is perhaps the best marine mammal to study using remote sensing techniques since it is gregarious and presents a large target which often has good visual and thermal contrast with its background. Also, an important component of its environment, the sea ice on which it hauls out, can be analyzed by remote sensing.

Quantitative analyses of the animals and the characteristics of their sea-ice habitat required detailed study of remote sensing imagery. This was not the first application of remote sensing techniques to the study of marine mammal populations. However, this was the first to use visual, ultraviolet and infrared imagery simultaneously. Previous studies have almost exclusively used visual wave length photography (e.g., Heyland, 1974; Sergeant, 1975), although ultraviolet photography has proved to be useful in assessing certain species of seals (e.g., harp seals, Lavigne and Øritsland, 1974). Infrared imagery has not proved to be very useful as a tool either for detecting or counting wild animals (Lavigne, Øritsland, and Falconer, 1977). Many animals use physiological adjustments and pelage insulation to maintain their surface temperatures at nearly ambient temperature and, therefore, there is little thermal contrast between the animals and their background (McCullough, Olsen, and Queal, 1964).

Walruses are ideal subjects for infrared imaging because: (1) they have sparse body hair; (2) there is little in their environment which could shield infrared radiation from the animals; and (3) there is a strong thermal contrast between the animals and their environment. (Surface temperatures are often as warm as 20° to 30° C, Ray & Fay, 1968). Infrared imagery, therefore, is an excellent tool for detecting walruses and has the potential for providing population assessments provided the resolution of the scanner is sufficient to distinguish individual animals.

The factors which influence the hauling out of walruses have been identified in previous work conducted from Eskimo skinboats, icebreakers, and aircraft. These factors include climatic conditions, activity patterns, and seasonally variable characteristics of the sea ice.

The general distribution of walruses and their habitat has been described from aerial and icebreaker surveys (Buckley, 1958; Kenyon, Fay, and Burns, pers. comm.). During the winter and early spring, the major concentrations of animals are in moderate to heavy pack ice southwest of St. Lawrence Island and near Bristol Bay. A few are scattered along the ice front between these two areas. Since the animals require access to open water, those on the pack ice are always associated with areas of active ice movements where new leads are constantly formed. During the remainder of the year the animals are found near the ice "front" or on land haul-out areas. The animals at the front haul out on ice floes, but prior to our study, no detailed analyses had been made of the sizes of floes on which the animals hauled out.

The most detailed study on the temporal patterns of walrus hauling out have been those of Fay and Ray (1968) and Ray and Fay (1968). They compared the circadian hauling-out patterns of wild and captive walruses and investigated certain physiological and behavioral aspects of hauling out. They found that

in the late winter and early spring wild walruses tended to haul out in the early morning and early afternoon and to be active in the water in the late forenoon and early evening. In contrast, summering male walruses on Round Island have been observed to remain hauled out for several days at a time and then to remain in the water for periods of up to several days (Miller, 1976; personal obs.). Other studies of walrus hauled out on land have shown a periodicity in the numbers hauled out over approximately a 10 day cycle (Taggart and Zabel, pers. comm., quoted in Estes and Gilbert, 1978).

Not surprisingly, several investigators have shown that the hauling-out behavior of several species of pinnipeds is influenced by environmental conditions (Burns and Harbo, 1972; Gilbert and Erickson, 1977; Sergeant, 1971). Every species of pinniped so far studied retreats into the water when climatic conditions in air place it outside its thermoneutral zone. For example, Fay and Ray (1968) report that walruses tend to haul out at air temperatures between -20 and +15° C if the winds are light and there is a moderate amount of sunshine.

Although walruses can be seen when they are swimming near the surface of the water, surveying animals in the water does not yield reliable population estimates. The probability of sighting animals in the water falls off much more rapidly with distance lateral to the flight line than it does for animals which are hauled out on the ice (Estes and Gilbert, 1978). Also, animals in the water are less concentrated and much more difficult to detect than those on ice.

The importance of being able to identify the type of habitat in which one can expect walruses to haul out is emphasized by Estes and Gilbert (1978). They demonstrated that because of the aggregated distribution of walruses, estimating the total abundance of walruses in any given area with a 95% confidence that the estimate is correct to within 10%, would require sampling 40% of the total walrus habitat area including a 100% sample of the area in which walrus occur at maximum density. According to present knowledge, the area which must be classified as walrus habitat is so large that walrus surveys conducted by traditional means could not provide the data ideally required for management decisions unless extremely extensive and costly surveys were to be undertaken. Therefore, we have attempted to define characteristics of the ice on which walrus haul out in order to better delimit areas of prime walrus habitat for better survey stratification.

In addition to stratification on the basis of ice type, another factor which must be considered in determining survey flight lines is whether the walrus tend to haul out on the same ice and move with it or whether they tend to maintain the same geographical position and haul out on different ice as it moves into the area. It is known that the geographical movement of ice in the Bering Sea, in response to currents and wind, can be up to 45 km per day (W. Campbell, pers. comm.). We have previously discussed the errors which can be introduced into population assessments when ice movements are not taken into consideration (Ray & Wartzok, 1974). In this report we provide some evidence that the walruses do indeed continue to haul out on the same pieces of ice over several days' time regardless of shifts in their geographical location. Previous surveys, conducted over periods of several weeks, may be in error because of lack of consideration of ice dynamics and walrus tendency towards site tenacity with regard to ice.

This investigation has been a "pilot study" in the application of remote sensing techniques to one marine mammal species. Some promising results have emerged, but they require validation. Further, the technologies we have employed need to be used to determine the breadth of their applicability to other species of marine mammals.

METHODS

The Study Area

The study area was Beringea, consisting of the Bering, Chukchi and western Beaufort Seas. Where we operated within this area was dictated by prior knowledge of the walruses' seasonal movements. Figure 1 shows the location of each series of remote sensing flights (15 flights total) and one icebreaker cruise. In September 1974 the flights were in four discontinuous areas and in April 1975 the flights were in two discontinuous areas. Table I lists the dates, locations, number of runs and data kilometers for each flight. A "run" was defined as a straight flight line with the aircraft level and all remote sensing equipment operating. Data kilometers were accumulated only during runs. Most of the flights were scheduled so that we were over the target area on data runs between 1100 and 1500 hours local time in order to experience the best sun angle for photography.

It is important to realize that these flights were not for censusing purposes and were not usually flown according to a predetermined grid. The primary goal was to determine the value, capabilities and application of remote sensing techniques for understanding walrus natural history. The general search area was determined by observations of the latest weather charts and satellite photographs of Beringea. After animals were located a raster flight pattern was flown as illustrated in Figure 8 (see page 25). We flew predetermined raster patterns only when we returned to an area on a succeeding day. The locations of the raster under those conditions was determined by predictions of the ice movement between succeeding flights (see below).

Remote Sensing Data Acquisition

Two different aircraft were used. In September 1974 we used an Elektra NP3, a twin-engine turboprop aircraft. This aircraft carried two Zeiss cameras (228.6 x 228.6 mm film image) with 152.4 mm focal length lenses providing a 73 degree field of view. We also had two KA-62 cameras (114.3 x 114.3 mm film image) with 3 76.2 mm focal length lenses which also provided a 73 degree

Figure 1. Locations of seasonal flights for September 1974, April 1975, August 1975, and April 1976 and cruise track of ground truth icebreaker survey in July 1977. The dashed circles represent the general areas of the flights. Often several flights occurred within the area denoted by one circle. The heavy solid line is the cruise track of the icebreaker USCGC _Glacier_ in July 1977.
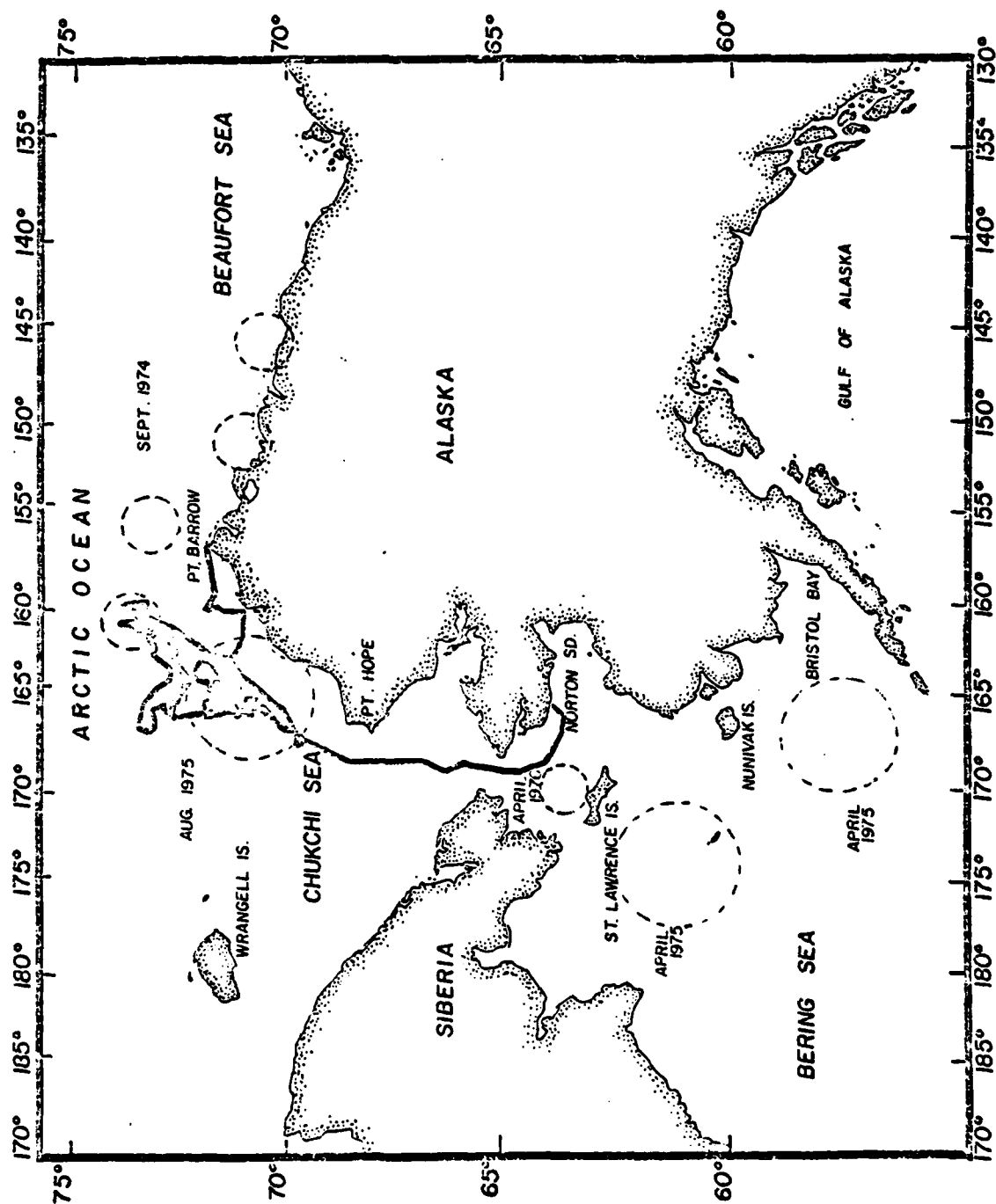
Figure 1

TABLE I. BESMEX Flight Summary

Date	Area	No. of Runs	Data Kilometers
8 Sept. 1974	Beaufort Sea	17	. 193
9 Sept. 1974	Arctic Ocean	9	180
20 Sept. 1974	Beaufort Sea (Smith Bay)	14	87
26 Sept. 1974	Beaufort Sea	2	13
5 Apr. 1975	Western Bering Sea (Ice Edge)	18	721
6 Apr. 1975	Bering Sea	8	1043
7 Apr. 1975	Bering Sea	14	647
8 Apr. 1975	Bering Sea	10	483
19 Aug. 1975	Chukchi Sea	6	367
23 Aug. 1975	Chukchi Sea (Barter I. and west)	19	705
24 Aug. 1975	Chukchi Sea	24	953
28 Aug. 1975	Chukchi Sea (Ice line along north coast of Alaska)	3	257
13 Apr. 1976	Bering Sea (St. Lawrence Is.; Bristol Bay)	7	338
18 Apr. 1976	Bering Sea St. Lawrence Island)	9	616
19 Apr. 1976	Bering Sea (North of St. Lawrence Island)	15	734
TOTALS:	15 flights	175 runs	7337 km

field of view. We tested two film types: SO 397 high-resolution color and 2443 false-color infrared. The NP also had a modular multispectral scanner system which recorded the same scene simultaneously and independently at ten different wavelengths from blue at 410 μm to 1015 μm in the infrared, in addition to one thermal infrared band. Black and white 70 mm transparencies could be made from each wavelength record. False-color images could be produced for any wavelength by transmitting light of different wavelengths through the black and white negatives.

The majority of the remote sensing data were acquired using the NASA Convair 990 Galileo II aircraft in April 1975, August 1975 and April 1976. This aircraft is a four-engine, jet-powered aircraft which provides a stable, relatively vibration-free platform for high resolution photography using a Wild RC-8 228.6 mm and a Wild KS-87 114.3 mm camera. Both cameras were loaded with Kodak SO 397 color film which the September 1974 flights had shown to be the best film for discriminating walruses from feces-stained ice. Both cameras were also fitted with HF-3 haze filters. The KS-87 camera had a 304.8 mm lens which gave a field of view of 21 degrees. The RC-8 camera had a 152.4 mm lens which provided a 73 degree field of view. We also obtained ultraviolet imagery using a 70 mm Hasselblad camera with a 105 mm quartz lens giving a 31 degree field of view. This camera was loaded with black and white Tri-X film which is sensitive to ultraviolet. We fitted the lens with a Kodak number 18A glass filter which does not transmit light of visual wavelengths.

The 9 inch and 5 inch cameras could be programmed so that pictures were taken with any predetermined amount of overlap between succeeding pictures. When we wanted total coverage of a flight track, we generally allowed a 10% overlap between succeeding frames. This is not sufficient overlap to provide for stereoscopic images, however. The camera with ultraviolet light sensitive film was also motor-driven but the motor was actuated manually whenever the aircraft flew over hauled-out walruses.

Both cameras had built-in clocks which provided a record of date and time on each frame. An on-board computer provided data every 10 seconds on: (1) the latitude and longitude coordinates as determined by the inertial navigation system; (2) the pitch, roll and yaw angles of the aircraft; (3) the altitude as determined by both pressure and radar altimeters; (4) the air speed, ground speed, wind speed and direction; and (5) the surface temperature as determined by a Barnes 14-325 infrared thermometer with a 2 degree field of view. A computer recorded this information at 20 second intervals.

During most of the data-collection runs, a Texas Instruments RS-310 infrared scanner provided a continuous record of the surface thermal radiation at a thermal resolution of 0.1 C and a spatial resolution of 5 milliradians. This scanner employs a mercury cadmium telluride detector sensitive to infrared radiation in the 8 to 14 μm band. Blackbody objects of 20° C surface temperature have the maximum energy of their emission at a wavelength of 9.9 μm. The real time output of the infrared scanner was displayed as a trace on an oscilloscope with the vertical deflection indicative of the temperature of the radiative surface in the field of view of the scanner. The scanner swept through an arc of ±45° on either side of the flight line. Walruses which were hauled out on the ice registered a deflection on the oscilloscope. These

"blips" were usually noted by the scanner operator, reported over the inter-com, and recorded on the computer printout. The scanner data were also recorded on 70 mm film. In addition, the detector signal levels were recorded on magnetic tape.

The infrared data which we used for analysis in this report were obtained by replaying the magnetic tapes and producing a 70 mm film transparency. This film looked a great deal like the 70 mm film which was recorded at the time of the aircraft flight except that the gray levels were set to provide a mini-mum contrast between the ice and the water which was just sufficient to allow identification of individual ice floes to coordinate with the visual photography. The main range of the gray scale was reserved to maximize contrasts within the areas of the walrus herds.

On every flight, in addition to NASA support personnel, there were at least three experienced marine mammal observers. One was stationed in the cockpit looking forward and the other two were on each side of the aircraft looking laterally through side windows located forward of the wings. Occasion-ally, a fourth observer was stationed in the belly of the aircraft between the cameras looking downward.

All verbal field notes and conversations that took place on the aircraft intercom system between investigators, pilots and technicians were recorded in an abbreviated form on the computer printout.

Ground Truth Data Acquisition

Our major source of ground truth data was from the 1977 Arctic Summer West cruise of the USCGC Glacier (see Figure 1 for cruise track). The ground truth studies were focused on environmental parameters when walruses were hauled out and when they were not. We also measured the surface temperature of hauled-out walruses.

Wind speed was measured both at the surface of the ice and 2 m above the surface of the ice with a Weathermeasure Corporation model W141 hot wire anenometer. The relative humidity was determined with a sling psychrometer. Air and water temperatures were determined with a Yellow Springs Instrument Corp. telethermometer using an air temperature probe number 405 for the air temperature measurement and a liquid immersion probe number 403 for the water temperature measurement. A third thermistor connected to the telethermometer was a small animal probe number 402 which terminated in the center of a black ping pong ball. The temperature reading from this probe was recorded as the equivalent blackbody temperature for that environment. The blackbody ping pong ball was made by cutting the ping pong ball in half and coating the inside and outside with optically flat black paint and then gluing the ping pong ball together again with the thermistor probe held in the center of the ball.

The walrus surface temperature measurements were taken with a Barnes PRT-10L infrared thermometer. The PRT-10L has a field of view of 2.8°. It is a hand-held instrument with a meter on the back indicating the surface temperature of whatever is in the field of view of the detector. This unit was calibrated with a Barnes calibration block before each series of tempera-ture measurements of the animals.

We approached the animals either from the water or by crawling across the ice floe on which they were situated until we were within 5 meters. At 5 meters the field of view of the PRT-10L covered 24 cm on the surface of the animal. Since the recorded temperatures were always an integration of the temperature in the entire field of view, we slowly deflected the radiation thermometer in one direction and then another in order to be sure we were focused on an area where there were no severe temperature gradients. The temperature readings were recorded in field notebooks at the time they were taken.

We also have acquired some ground truth data from Mr. Tom Eley who accompanied St. Lawrence Island Eskimos in their skin boats when they were hunting walruses in 1975-6. He measured wind speed with the Weather-measure hot wire anenometer, air and water temperatures with a thermometer, and the surface temperatures of hauled-out walruses with the Barnes radiation thermometer.

Ice Movement Predictions

In April 1975 we predicted the movement of the ice on subsequent days so that flights could survey the same ice and associated walrus concentrations. The method for ice movement prediction is that of William J. Campbell (pers. comm.). From the CV-990 inertial navigation system we obtained the coordinates of the ice occupied by the walrus on the first day. That evening, we obtained the surface (or preferably, the 900 millibar) charts for the time closest to the time of obtaining coordinates of the walrus herd. We determined the atmospheric pressure gradient at the location of the walrus herd from the spacing of the isobars in that area. The direction of the air vector was assumed to point 90° clockwise from the direction of the high-to-low pressure gradient vector. The magnitude of the air vector was determined from the nomogram on the pressure chart used. Figure 2 was used to determine the drift speed of the ice. The direction of the ice drift vector was assumed to be the same as that of air vector (Zubov approximation). A new vector was calculated for every 6 hour update of the pressure charts. The final location of the ice with the walrus was predicted from the vector summation of all the 6 hour drift vectors between our two successive survey flights.

Photographic Analysis

The 5 and 9 inch color transparencies and the 70 mm black and white transparencies from the infrared scanner were viewed on Richards 918LW light table. An Olympus SV-IV binocular zoom microscope provided magnifications of 7X to 40X and was used for viewing selected portions of the films. An additional home-made light box was used to illuminate the 70 mm infrared scanner output film when we were comparing the walruses detected by the infrared scanner with those detected by visual inspection of the 5 and 9 inch films.

We determined the percent cover of different categories of ice in frames

---

Figure 2. Ice drift velocity as a function of wind speed. The chart is based on a roughness parameter of 0.2 and is for winds measured at a height of 15 m above the surface of the ice. Redrawn from Campbell.
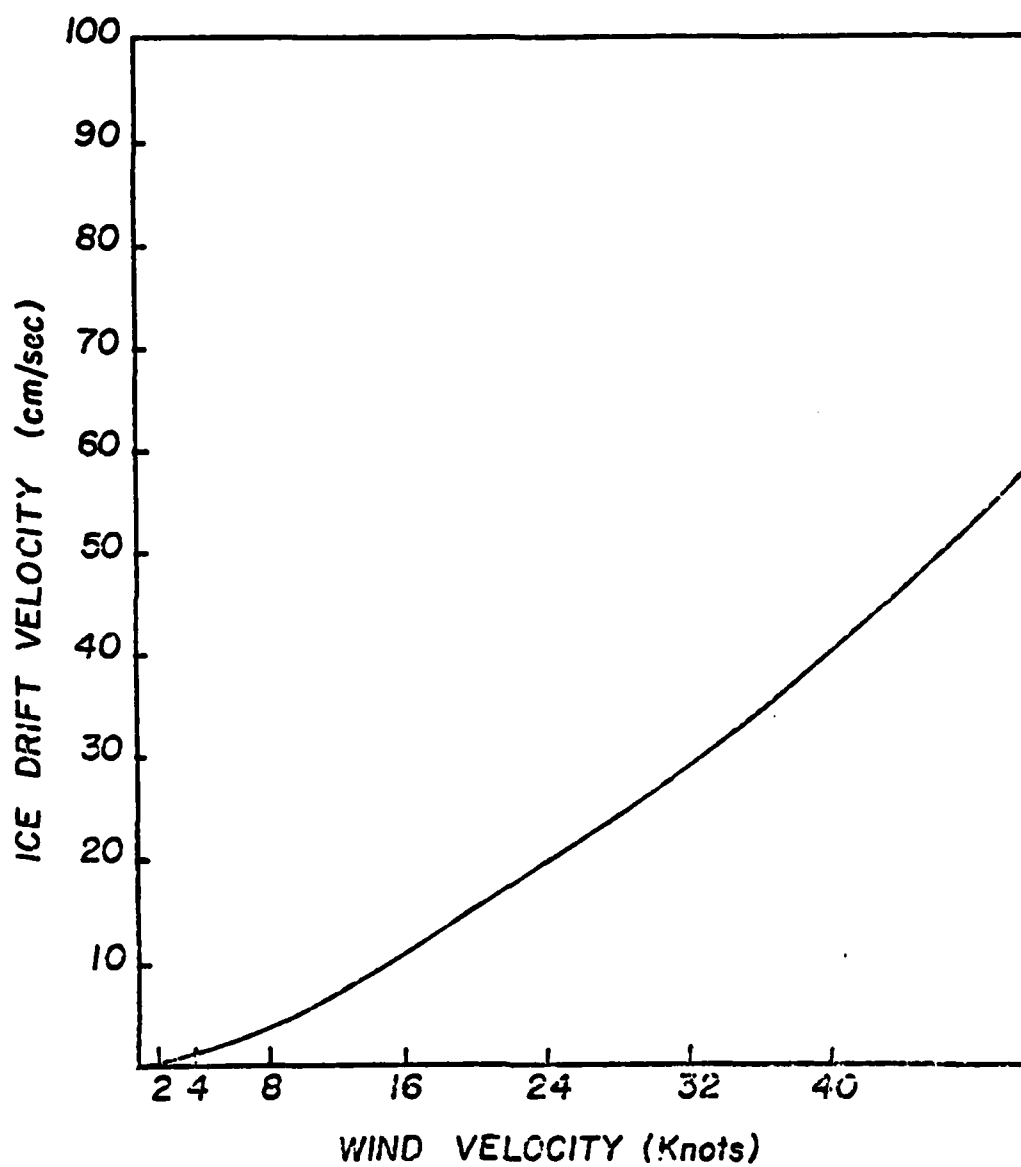
Figure 2

from April 1975 and April 1976. We used two different methods to determine
these percentages. By the first method, the ice was classified into two
broad categories: (1) white ice which was judged to be ice thick enough to
support walruses and (2) ice not sufficiently thick for hauling out, includ-
ing grease, grey, and grey-white ice, and open water. Acetate overlays were
placed on each frame and the outline of the area not thick enough to support
walruses was drawn on each overlay. These outlines were then filled in
with black ink and each acetate sheet was passed through a Li-Cor Model
3100 Area Meter which gave a reading of the inked area in square centimeters.

The second method used was a categorization based on a line transect down
the center of each frame. Along this line we noted each change of the ice
from one category to another and measured the lengths of the line transects
which were occupied by each of four different categories: (1) open water;
(2) grey ice which we judged to be ice thin enough to allow the walruses to
break through if they needed to surface for a breath--a maximum of about 10 cm
thick; (3) grey-white ice--too thick for walruses to break through, but not
thick enough for hauling out; and (4) white ice, judged to be in excess of
75 cm--thick enough for walrus hauling out. We make no claim to having iden-
tified the ice thickness precisely. Indeed, ways of measuring ice thickness
through remote sensing techniques are the subject of much current investiga-
tion. Although not in accord with WMO ice typology, these categories are
appropriate to walrus natural history.

In analyzing the September 1974 and August 1975 photography we concen-
trated on measuring the size distributions of the floes on which the animals
were hauled out in comparison to the size distributions of floes in the imme-
diate vicinity on which they did not haul out. We also measured the distribution
of floe sizes from areas where no walruses were encountered. Floe size measure-
ments were made by drawing an outline of each floe on an acetate overlay, lay-
ing the overlays on a square grid of 20 lines per inch, and counting the num-
ber of squares within the outline. Squares with greater than half their area
inside the outline were included in the count whereas squares with less than
half of their area inside the outline were excluded from the count. These
counts were translated into actual areas of ice floes through the following
calculations.

$$F = (2\ H\ \tan(V/2))^2$$

where F = footprint of each square photographic frame

H = altitude of the aircraft when the photograph was taken

V = field of view of the camera.

For a camera with a 73° field of view and a 9 inch (228.6 x 228.6 mm)
film image, the footprint in m^2 given the aircraft in feet is

$$F = (0.235)H^2$$

For a grid with 20 lines to the inch, the area of the 9 inch frame
was $(9 \times 20)^2 = 32,400$ squares. Hence

$$G = (6.28 \times 10^{-6})H^2$$

where G = footprint in m^2 per square of the grid paper

H = altitude of the aircraft in feet.

Walrus Pelage Reflectance Measurements

Skin samples from walrus male, female and pup back, belly and flipper were stretched and dried but not tanned. The reflectance characteristics at wavelengths from 0.3 to 2.5 µm were determined at .100 µm intervals using a Beckman DK-2A spectrophotometer in the spectroreflectometer configuration. The spectrophotometer determined the reflective properties of each sample by measuring the difference in reflectivity between the sample and a white reference block of magnesium carbonate, a perfect reflector. Measurements were taken at five adjacent locations on each sample and averaged.

RESULTS

Remote Sensing of Walrus on Ice

The questions addressed in this section are: (1) What are the relative values of visual, infrared, ultraviolet, and overlayed multispectral remote sensing imaging techniques for detecting and counting hauled-out walruses? (2) What is the best film for use in the visual spectrum? and (3) What is the optimum aircraft height for detecting and counting hauled-out walruses?

1. Visual photography: On flights in September 1974, we used both high-resolution color film (Kodak SO-397, 80 lines/mm for 1000:1 contrast ratio) and false-color infrared film (Kodak 2443) to see which film gave the best detection capability for hauled-out walruses. The color film was far superior to the false-color infrared. These observations were confirmed by results from many simultaneously photographed scenes under a variety of sun angles. On all subsequent flights we used only high-resolution color film.

2. <u>Infrared</u>: We correlated 23 walrus groups detected by infrared scanning with those identified by an initial examination of visual photography from 18 and 19 April 1976. These represented only 77% of the total presumptive walrus groups detected by the scanner. An additional 4 (13%) groups of walrus detected on the infrared had not been noticed on our initial examination of the visual photography. These groups had from 1 to 10 animals in them. On the other hand there were 2 (7%) instances in which the infrared scanner indicated a hot spot on the ice which we were unable to associate with anything on visual photography. Thus the infrared scanner may have generated some false positives. Finally there was one instance (3%) in which a hot spot was registered on the infrared scanner which the visual photography showed was an unoccupied walrus haul-out area. Usually, haul-outs with very dark feces-covered ice showed no temperature difference from the background. Therefore, the scanner was probably responding in this case to a haulout which had been very recently vacated by the animals.

Results from flights on 23 and 24 August 1975 showed that only 12 (46%) of the infrared detected walrus groups had previously been identified on the visual photography. There were 14 (54%) which had not previously been identified on the visual photography, but which were later located by detailed review of scanner and visual photography together. The missed groups were either small or scattered out among the small floes at the ice edge. Our logs of observations taken during the flights showed that we had also failed to observe these groups visually when we were flying over them. Thus, large groups of walruses can be readily detected by either visual observations or by photography. However, small groups are much more easily detected with the infrared scanner, particularly when the ice background is broken up into many small floes or is darkened by algae, feces, etc.

Although the infrared scanner represents a significant improvement over visual sighting or visual photography for detecting hauled-out walruses, it was not very efficient in determining the number of hauled-out walruses. Neither the real-time "blips" nor the images on the 70 mm scanner film proved to be an accurate indication of the number of animals hauled out. Since hauled-out walruses are often in contact with each other or separated by less than a meter, it is not surprising that the infrared scanner, with its 5 milliradian spatial resolution, is unable to distinguish individual animals. The temporal duration of a blip or the size of the image on the 70 mm film does increase with increasing group size but more data are required to demonstrate whether a correlation can be made between image size and walrus numbers.

The infrared radiation from the animals was effectively absorbed by any clouds so the scanner did not detect hauled-out walruses if clouds were between the aircraft and the animals. However, since the scanner sensed emitted rather than reflected radiation, it performed just as well at night as during the day.

3. <u>Multispectral</u>: During the September 1974 flights, we used a modular multispectral scanner (M^2S) to determine if there was a combination of wavelengths at which walruses could be differentiated from the feces-stained ice of their haulouts. One combination of sensing wavelengths and viewing

illumination provided good separation of walrus herds from the background.
When the number 4 band (560 µm) photograph was illuminated with light passed
through a red Kodak number 29 Wratten filter and the number 10 band (1015 µm)
was illuminated with light passed through a green Kodak number 64 Wratten
filter, the ice appeared green, the feces on the ice appeared orange and the
walruses a dim red. Thus there is a combination of wavelengths at which the
walruses can be differentiated from the feces-stained ice upon which they
are hauled out. However, it was difficult and time consuming to get the
separate M^2S images in register. Also the M^2S was only available on the air-
craft we used in September 1974. Thus we did not pursue this method of dis-
tinguishing walruses from their feces-stained haulouts, despite its potential.

4. <u>Ultraviolet</u>: On flights in April 1975 and August 1975 we tested
whether hauled-out walruses could be distinguished from their background when
the photographing wavelengths were limited to the ultraviolet region of the
spectrum. In no case were we able to detect hauled-out walruses on photographs
taken when we were directly over herds of hauled-out walruses. This result
confirms some earlier tests we had conducted at Round Island in July 1974 where
hauled-out male walruses were shown not to be in strong contrast with their
background by ultraviolet light photography. Walruses absorb almost all of
the ultraviolet light falling on their pelages (Table II). Apparently, so does
their background of feces-covered ice or a rocky shoreline.

5. <u>Flight altitudes</u>: We tried several altitudes in order to determine the
tradeoffs between footprint and resolution of the remote sensing imaging systems.
The minimum speed of the CV 990 during data runs was 240 knots which meant that
300 m was the minimum altitude at which we could fly and still retain motion
compensation for the cameras and scanner.

We also tested the equipment at 900 and 1500 m. Individual animals could
not be discriminated at 1500 m. At 900 m the KS-87 camera with the 304.8 mm lens
allowed discrimination of individual animals but we could not consistently dis-
criminate individuals on the imagery from the RC-8 camera with the 152.4 mm lens.
At none of these altitudes could individuals be discriminated by the infrared
scanner. Groups could be detected by the scanner at all altitudes tested.

Based on these tests, most of our flights were conducted at 300 or 450 m
altitude where we could distinguish individual animals on the visual photography
from both camera systems.

Hauling-Out Behavior of Walruses

This section consists of three subsections. First, we describe those
characteristics of walrus hauling-out behavior which were basically the same
during the non-migratory periods of late winter and the late summer. Second,
we detail aspects of hauling-out behavior which appeared to be unique to the
late winter ice and habitat conditions. Finally, we present those behaviors
which appear to be limited to the particular ice conditions observed in the
late summer.

1. <u>Seasonally Invariant Walrus Hauling-Out Behavior</u>

1.a. <u>Ice site tenacity</u>: In both April 1975 and July 1977 we obtained

TABLE II. Reflective properties of walrus pelage (percent reflected).

Wavelength (μm)	Male			Female			Pup		
	Back	Belly	Flipper	Back	Belly	Flipper	Back	Belly	Flipper
.3	0	0	0	0	0	0	0	0	0
.4	5	5	4	4	5	4	5	5	5
.5	15	14	15	14	14	14	15	14	15
.6	23	23	23	23	23	23	22	23	22
.7	32	31	32	31	32	31	33	31	30
.8	43	43	43	43	42	43	42	42	43
.9	49	49	49	49	49	51	50	51	50
1.0	52	51	52	51	51	51	51	50	50
1.1	55	55	54	55	54	52	53	53	54
1.2	48	48	48	48	48	50	49	49	50
1.3	54	54	54	54	54	54	53	55	54
1.4	45	43	43	45	45	44	44	44	44
1.5	34	34	33	34	34	34	33	33	34
1.6	39	38	37	39	39	39	37	39	40
1.7	35	34	34	34	34	34	34	35	35
1.8	35	35	35	35	34	34	34	34	34
1.9	29	28	30	28	29	30	30	29	30
2.0	20	20	21	20	20	21	20	20	20
2.1	21	23	21	21	21	21	21	22	21
2.2	17	18	19	17	17	17	18	17	17
2.3	15	15	14	15	15	17	16	16	16
2.4	15	15	15	15	15	17	15	15	15
2.5	14	12	12	12	13	14	12	13	13

evidence indicating that walruses sometimes maintain their position relative to a given area of ice even though that ice moved in response to current and wind-stress fields.

In April 1975 we flew a 60 by 52 km grid on three consecutive days, 6, 7, and 8 April (Ray and Wartzok, 1975). This grid shifted 11 km to the southeast between successive flights. (See methods for calculation of ice movement.) The location of the walruses relative to the grid was relatively constant over these three days, as illustrated in Figure 3. On the 6th of April, the first day we were able to fly after several days of stormy weather, we visually estimated 437 walruses hauled out in this area. On that day, weather conditions were still unfavorable for hauling out with overcast skies and high winds. The winds moderated on succeeding days and insolation increased steadily. On the 7th of April, the ice area had shifted 11 km to the southeast and we visually estimated 1200 animals. On the third day, 8 April, the area of walrus concentration had shifted an additional 11 km, and we visually estimated 9479 animals hauled out.

Since none of the animals were marked or radio tagged, it is impossible to prove conclusively that the same animals were present on the same ice from day to day. However, this is the most reasonable hypothesis for the following reasons. First, as illustrated in Figure 3, we surveyed an area quite a bit larger than the area of walrus concentration and detected only a few animals hauled out on the ice or swimming in the water elsewhere in the grid. Second, observations along flight lines to and from the grid of data runs detected very few animals. Finally, there were many holes in the grey ice in the area of the walrus concentration. These holes are made by walruses surfacing to breathe. Few of these holes were observed outside of the area of the walrus concentration. Thus, we feel certain that the numbers of walruses in that area did not change, but rather that the proportion hauled out changed.

We obtained similar information of walrus site tenacity relative to ice in July 1977 during our icebreaker "ground truth" study. Repeated helicopter flights, during which we became quite familiar with the sea ice of the area, and incredible serendipity strongly indicated this site tenacity over a period of three days and a change in the ice's geographical location of 13 km. We had been following a large group of walruses during this period. On the 16th of July we made our first attempt at radio tagging a walrus. During this attempt a marked film canister was found on the ice close to the walrus group. This accidental marking of the ice proved that we were indeed looking at the same ice on both occasions. Again, we cannot conclusively prove that the same walrus were occupying

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Figure 3. Shifting flight grid and area of walrus concentration in April 1975. The rectangular outline shows the limits of the survey grid for each flight. Within each flight grid the dashed circle is the area of walrus concentration. Our calculations of sea ice movement which dictated our shifting of the flight grid from day to day resulted in the area of walrus concentration remaining stationary so far as its location within the grid was concerned. The displacement of the ice, walrus concentration and flight grid was 11 km to the southeast on each succeeding day.
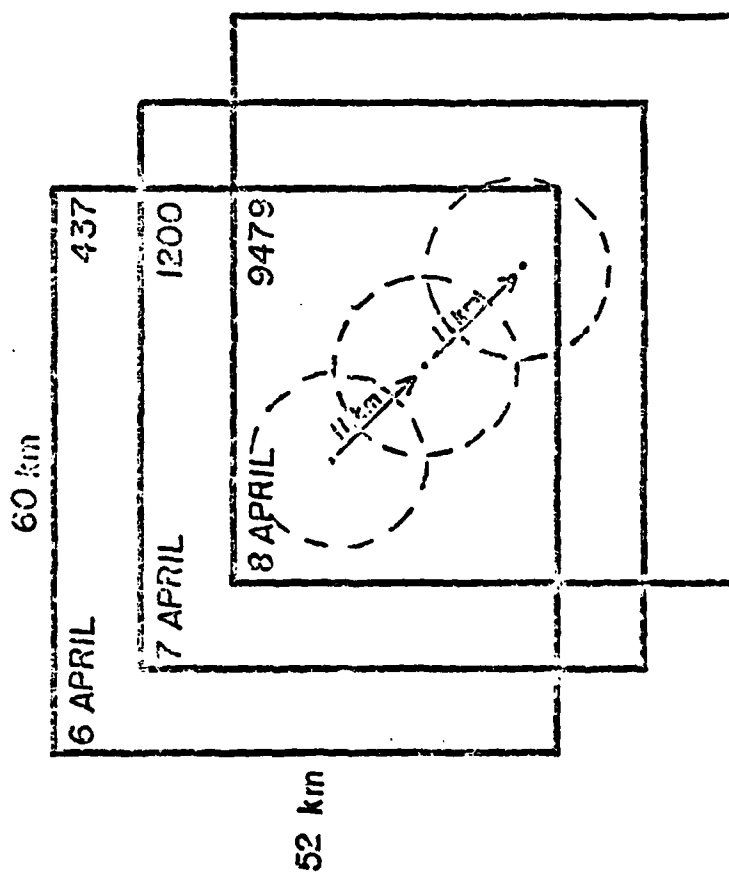
18

6 APRIL
7 APRIL
8 APRIL

437
1200
9479

60 km
52 km

11 km
11 km

Figure 3

the same ice on these two occasions. However, the aerial surveys revealed that there was basically one concentration of walruses in the area which we followed for 12 days (see Synchrony and Periodocity of Hauling-Out Behavior below).

Certainly walruses do not strictly maintain their position relative to the individual floes of ice, migration of Spring and Fall being cases in point. The walrus concentration we followed from the icebreaker would sometimes be one large herd and at other times it would separate into a number of smaller herds located up to 21.3 km apart. Also when we compared the ship's position with the location of the ice front as determined from satellite photographs, we determined that this walrus concentration moved up to 24 km relative to the ice during the 12 days we followed them.

1.b. <u>Group sizes of hauled-out walruses</u>: Group sizes recorded in September 1974, April 1975 and August 1975 were distributed as truncated negative binomials (Figures 4 and 5). Only for April 1976 did the frequency distribution of the different group sizes differ from a truncated negative binomial. In this case, there was an underrepresentation of the single animal group size class.

For each distribution the maximum likelihood estimates for the parameters (w and k) of the truncated negative binomial were determined iteratively as outlined in Sampford (1955). After the parameters were determined, the truncated negative binomial distribution was used to predict the number of occurrences of any group size based on the total number of groups observed for a given series of flights. The actual frequency distribution of group sizes was compared to that predicted by the truncated negative binomial using a chi square test. The results on group size distributions are summarized in Table III.

2. <u>Hauling-Out Behavior in Late Winter</u>

2.a. <u>General habitat description</u>: In the late winter walruses prefer to cluster in the pack ice some distance from the front. Within the pack ice, the animals select areas of dynamic ice movements where leads are opening and closing in response to changes in wind, currents, and weather conditions. Leads are usually oriented in a northwest to southeast pattern in the south central Bering Sea. It is our strong impression that walruses in that area generally cluster in several groups of varying sizes at branching points in lead systems.

2.b. <u>Ice characteristics of haulout areas</u>: The questions addressed in this section are: (1) Does the sea ice on which walruses haul out differ in any consistent way from ice in the same general area on which walruses are not

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<u>Figure 4</u>. Distribution of walrus group sizes for September 1974 and August 1975.

<u>Figure 5</u>. Distribution of walrus group sizes for April 1975 and April 1976.

T A B L E   I I I

WALRUS GROUP SIZE DISTRIBUTION PARAMETERS

| Flight Series	Figure Illustrating Group Size Distribution	Group Size Range	Truncated Negative Binomial Parameters		Chi Square Value	Degrees of Freedom	Signifi- cance
			w	k			
Sept. 1974	Figure 5	1 – 107	0.0958	1.1198	7.38	9	N.S.
April 1975	Figure 6	1 – 133	0.0376	0.3325	8.71	10	N.S.
Aug. 1975	Figure 5	1 – 194	0.0409	0.6926	15.85	10	N.S.
April 1976	Figure 6	1 – 157	0.0641	0.3192	19.18	8	$p < 0.025$

Figure 4

GROUP SIZE
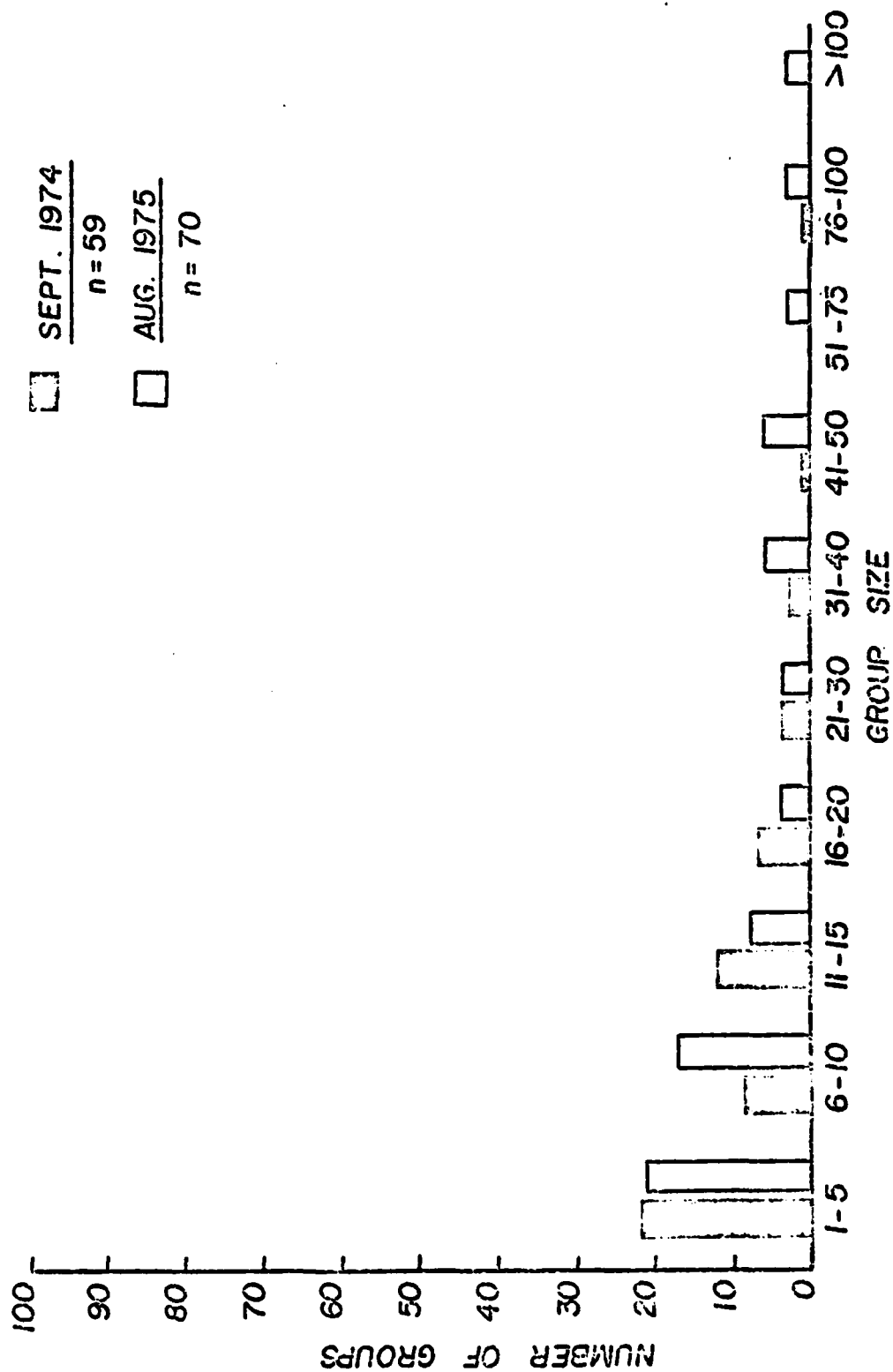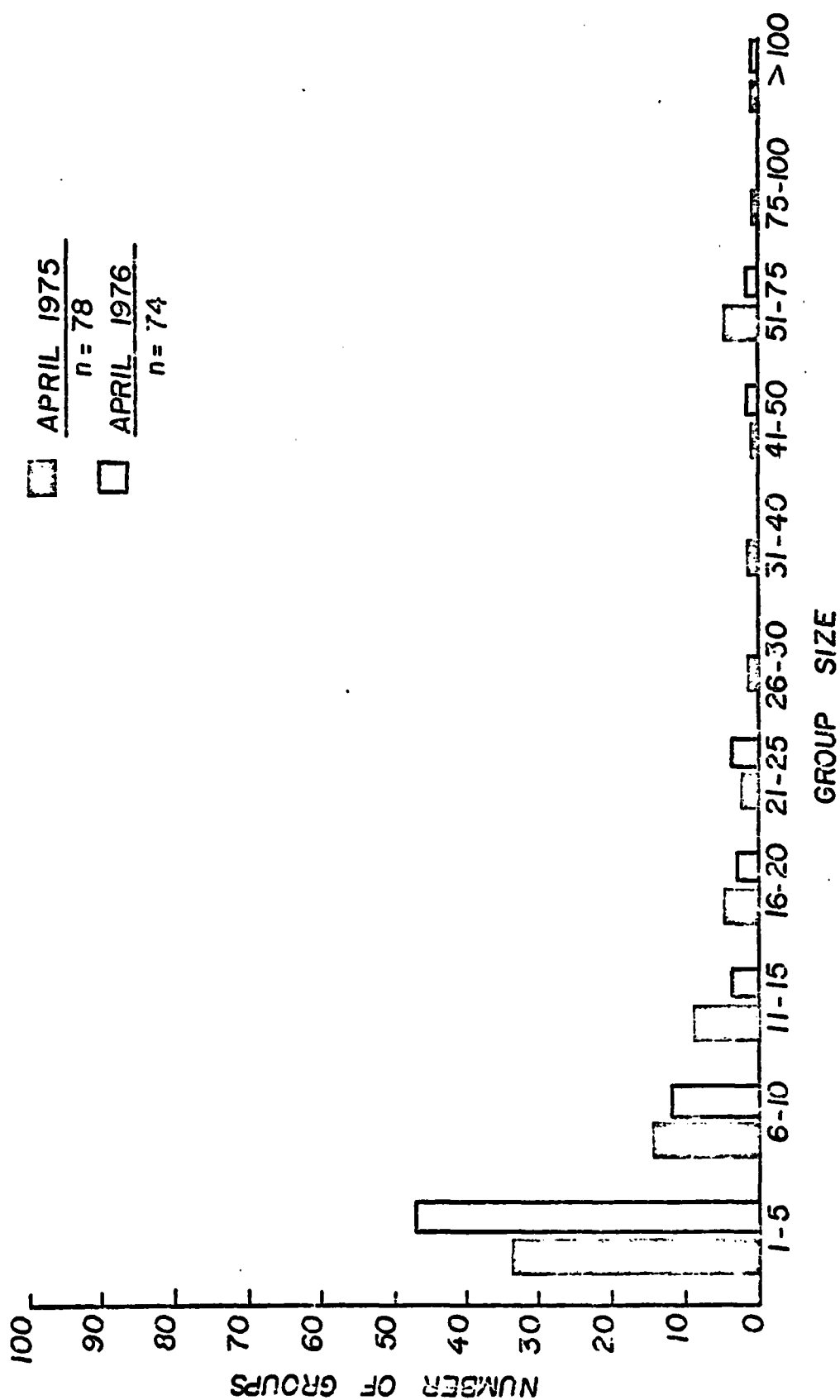
Figure 5

hauled out? and (2) Can the data obtained from one year on preferred sea ice characteristics be used to predict where walruses will haul out in another year?

We first analyzed data from 18 April 1976 since this was the one for which we had the best photography. Figure 6 shows the flight lines on that date and the numbers of walruses observed. Each flight line, with the exception of number 6 which was a repeat, was divided into 10 equal lengths and one 22.86 cm square photograph taken at the center of each of these segments was analyzed. The actual surface area photographed on each frame was 1,831,260 m^2. The area on each frame corresponding to open water or ice on which walruses could not haul out was determined by using the Li-Cor. Within grid parallelograms 5, 6, 10, and 14 in which 37.5, 50.9, 5.2, and 5.8% of the hauled-out walruses were observed, the mean area per frame for open water and ice not sufficiently thick to support walruses was 157,125 ± 253,460 m^2 (n=12). In the remainder of the grid parallelogram the mean area per frame for open water and ice not sufficiently thick to support walruses was 412,880 ± 408,637 m^2 (n=68). These means were not significantly different at the 0.05 level (SNK test, Sokal and Rohlf, 1969). Hence we concluded that with the sample size we used, a two level categorization of the ice on the basis of areas in each category was not sufficient to discriminate between areas with hauled-out walruses and those without.

The second analysis was a discriminant analysis (Klecka, 1975) based on four levels of categorization of the sea ice (see methods). The ice categorization was done on a line transect down the center of all the photographs taken while on data runs on the flights of 18 April 1976 and 8 April 1975 (see Figure 7 for flight lines). We had complete photographic coverage for all data runs on these flights. The four discriminating variables used in the analysis were the lengths of the line transect in each grid parallelogram assigned to the four categories of ice thickness.

The results of the discriminant analysis can be best understood by describing in some detail the technique as applied to April 1976 data for the analysis portion of discriminant analysis and as applied to April 1975 data for the classification portion of discriminant analysis. Readers unfamiliar with the technique should consult Klecka (1975) or some other discussion of discriminant analysis. Parallelograms for April 1976 were divided into three groups: Group I which contained less than 2% of the observed hauled-out walruses (grid parallelograms 1, 2, 3, 4, 7, 8, 9, 11, 12, 13, 15, and 16); Group II which contained between 2 and 10% of the observed hauled-out walruses (grid parallelograms 10 and 14); and Group III which contained greater than 10% of the observed hauled-out walruses (grid parallelograms 5 and 6). In the analysis portion of discriminant analysis, the four discriminant variables are weighted and linearly combined so that the three groups of parallelograms with the different proportions

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Figure 6. Flight lines for 18 April 1976. The entire survey grid is divided into 16 equal parallelograms.

Figure 7. Flight lines for 8 April 1975. The entire survey grid is divided into 16 equal parallelograms.
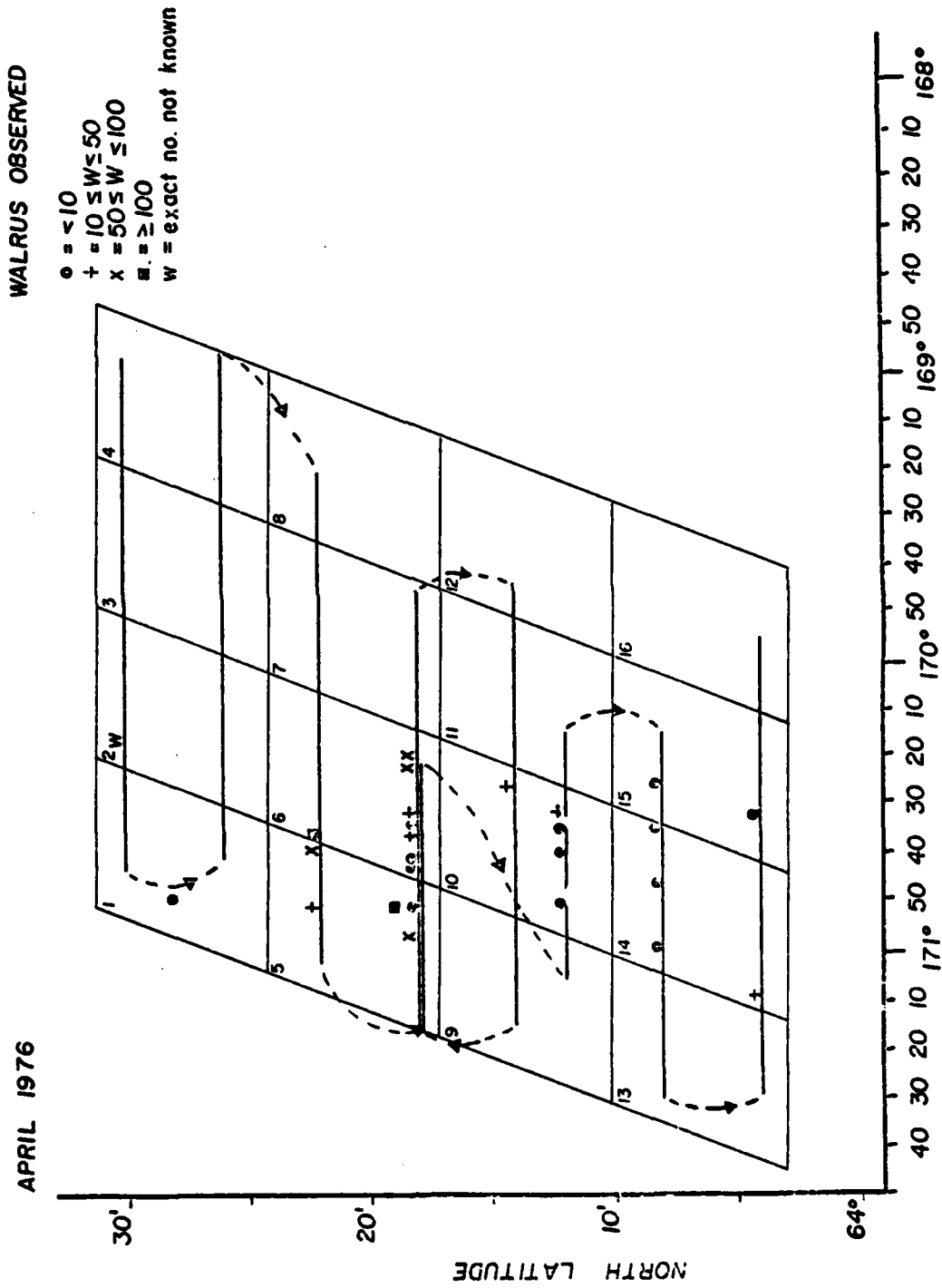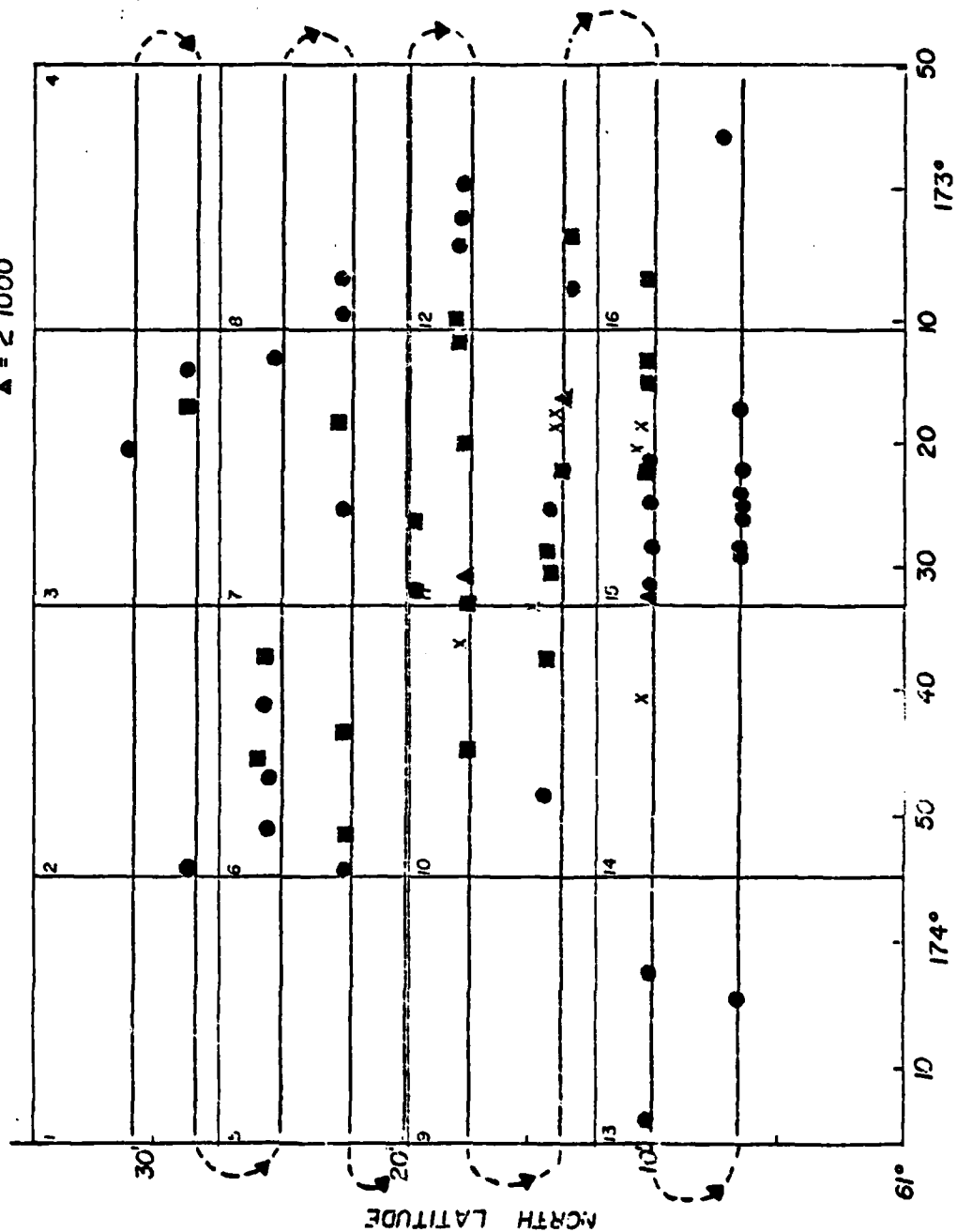
WALRUS OBSERVED

● = <10
+ = 10 ≤ W ≤ 50
X = 50 ≤ W ≤ 100
■ = ≥ 100
w = exact no. not known

APRIL 1976

NORTH LATITUDE

WEST LONGITUDE

Figure 6

WALRUS OBSERVED

● = <100
▣ = 100 ≤ W < 400
X = 400 ≤ W < 1000
▲ = ≥ 1000

APRIL 1975

WEST LONGITUDE
Figure 7

NORTH LATITUDE

of observed hauled-out walruses would be as statistically different as possible.
The analysis portion was done in a stepwise fashion in which the single dis-
criminant variable which best separated the three groups is entered first.
Then additional variables are entered stepwise always on the basis of which
variable when added to the discriminant function gives the best criterion
score. The criterion used was Wilk's criterion which maximizes the overall
multivariate F ratio for the test of differences among the group centroids. The
analysis portion indicates which of the discriminant variables are most important
for discriminating between the different groups and also how well the groups can
be separated on the basis of the discriminant variables chosen.

For the April 1976 data the results were that the amount of open water was
the best discriminant variable between the three groups. The second most impor-
tant discriminant variable was the amount of thin ice and the third was the
amount of solid, thick ice. The amount of ice in category 2, not thick enough
to support a hauled-out walrus but too thick to break through to breathe, does
not contribute to the discrimination of the three groups. The three discrimi-
nant variables used do provide good separation for the three groups with all
the parallelograms containing more than 10% of the hauled-out walruses correctly
classified, all the parallelograms containing 2 to 10% of the observed hauled-out
walruses correctly classified, and 9 of the 12 parallelograms containing less
than 2% of the observed hauled-out walruses correctly classified. The three of
Group I which were incorrectly classified were placed in Group II.

The second phase of the discriminant analysis is the classification phase.
Using the discriminant functions determined for April 1976, how well can we pre-
dict into which group each parallelogram from the April 1975 grid will fall?
Here we were much less successful. Of 8 parallelograms which fell within
Group I, only 4 were classified correctly. Of the 4 incorrectly classified, 1
was put in Group II and 3 were put in Group III. Of the 6 parallelograms which
fell within Group II, only 1 was correctly classified. Of the 5 incorrectly
classified ones, 4 were put in Group I and 1 in Group III. Finally, of the 2
parallelograms which fell within Group III, both were misclassified into Group I.
Thus, only 5 of 16 April 1975 parallelograms could be correctly classified as
to the relative proportion of hauled-out walruses they would contain based on
the ice characteristics which provided good classification for hauled-out wal-
ruses in April 1976.

The second discriminant analysis test was basically the reverse of the first
in that the discriminant functions were set up based on the ice characteristics
in April 1975. In this analysis the amount of ice in category 2, not thick enough
to support a walrus, but too thick for walruses to break through to breathe, was
the best discriminant variable. The next best was the amount of ice thick enough
for walruses to haul out on. Neither the amount of open water nor the amount of
thin ice added to the discriminating power. For April 1975, the two discriminant
variables do not provide good separation of the three groups of grid parallelo-
grams based on the relative proportions they contained of the observed hauled-out
walruses. The discrimination was so bad that there is no point in detailing the
errors. Seven of 16 parallelograms from April 1975 were misclassified. When the
discriminant functions derived from April 1975 data were applied to April 1976
data, 13 of 16 parallelograms were misclassified.

3. Hauling-Out Behavior in Late Summer

The sea ice in the areas where walruses were hauled out in late summer had very different characteristics from the sea ice in the areas of hauled-out walruses in late winter. In the late summer, ice floe size appears to be a determining factor in walrus hauling-out behavior. Hence, this section examines the distribution of floe sizes available at that time of the year as well as the distribution of floe sizes on which walruses haul out. Other factors associated with the floes for which we present data include: the number and density of animals on each floe, the percentage of the flow occupied by walruses and the orientation of the animals on individual floes. We also present some data acquired from the icebreaker cruise which shows synchrony and periodicity in walrus hauling-out behavior at this time of the year.

3a. **General habitat description**: In contrast to April when the animals are usually several miles in from the ice front, in July through September walruses remain near the front. At this time of the year, the form of the front is highly dependent on the direction of the prevailing winds. Northerly winds may disperse the ice over 10-20 km, whereas a southerly wind may compact it to a sharply demarcated line.

3b. **Occupied and unoccupied floe sizes**: Walruses were observed hauled out on floes which ranged in size from less than 10 m^2 to as large as 30 hectares. The first question we addressed was whether the walruses were hauling out indiscriminantly on the floes available or whether the distribution of occupied floes differed from that of unoccupied floes.

We chose to look at the floe size distribution at two different scales. In the first case, which we called the "large grain distribution," we looked along the flight line at three 22.86 cm frames on each side of the frame which contained the hauled-out walruses. This is equivalent to looking at a strip 2 km long on either side of the location of the hauled-out walruses on photographs taken from 450 m. The "small grain distribution" is the distribution of floes in the same 22.86 cm frame as that having the hauled-out walruses. These two floe size distributions were compared with each other as well as with the distribution of floe sizes upon which walruses were actually hauled out. These comparisons were done from photographs taken on the September 1974 and August 1975 flights. Figure 8 shows the large grain distribution for September and August. These distributions are significantly different ($x^2 = 26526$, df = 12, p < 0.001). The September distribution has its peak in the category of small ice floes from 1 to 25 m^2 and the August distribution peaks at floe sizes between 400 and 800 m^2. Figure 9 shows the small grain floe size distribution comparison for September and August.

Figure 8 . Distribution of the sizes of ice floes without walruses in three 22.86 cm frames along the flight line which were on either side of frames which contained hauled-out walruses. Distributions are shown for both September 1974 and August 1975.

Figure 9 . Distribution of the sizes of ice floes without walruses within the 22.86 cm frames which contained hauled-out walruses. Distributions are for September 1974 and August 1975.
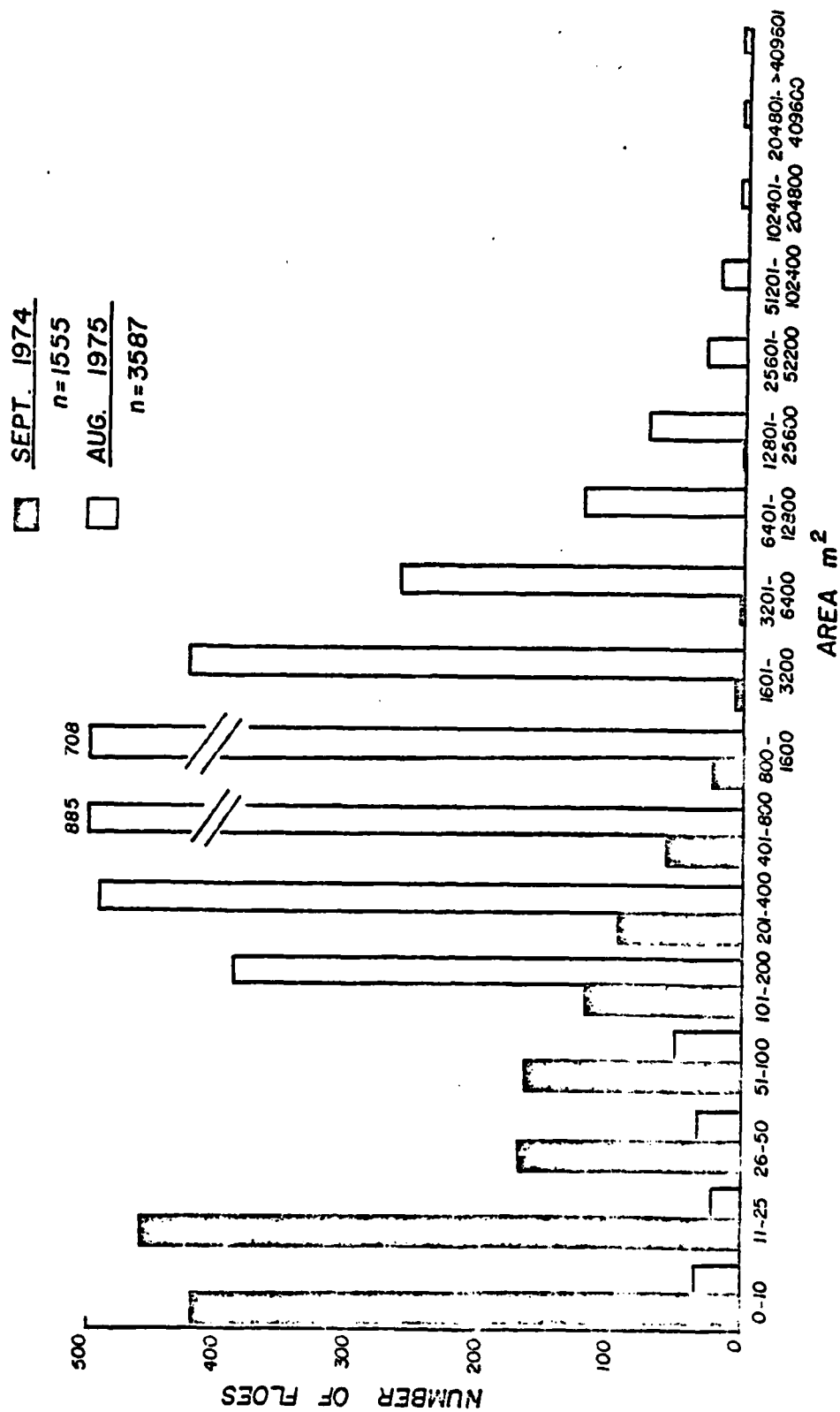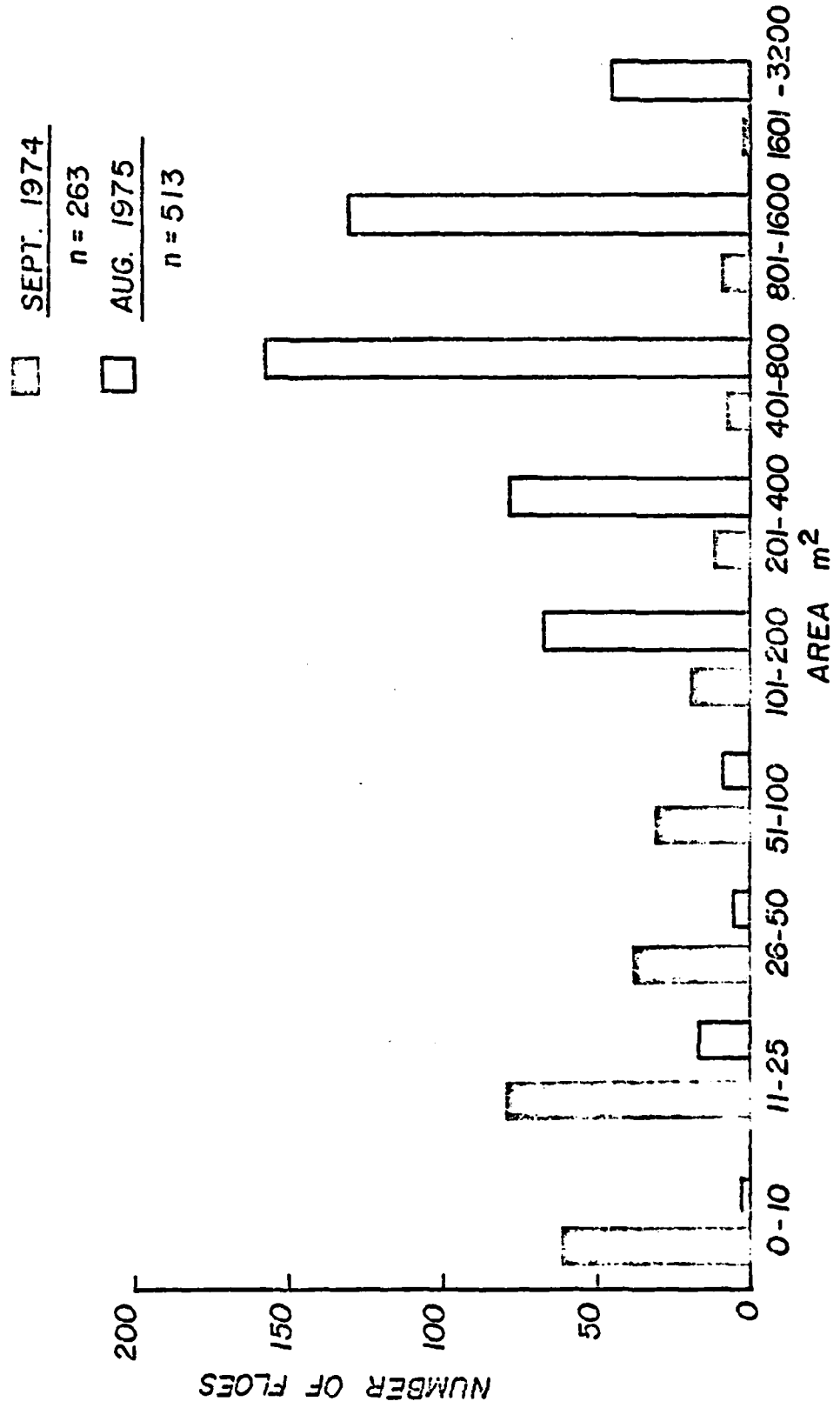
Figure 8

Figure 9

Basically, there is little difference between the small and large grain distributions for either month, i.e., the distribution for September small grain is very similar to the September large grain distribution. For August there is a bimodal distribution in floe size with peaks at 11-25 and 401-800 m^2. The large difference in floe size distribution again occurs in the comparison between September and August (X^2 = 2246, df = 5, p < 0.001).

Figure 10 compares the distributions of sizes of floes which were occupied by walruses in September 1974 and August 1975. In September the occupied floe distribution is unimodal with a peak between 100 and 200 m^2. There are very significant differences between the occupied floe distribution in September and the large grain floe distribution in September (X^2 = 85, df = 2, p < 0.001). Similarly, the comparison between the occupied floe size distribution in August and the large grain distribution shows a significant difference (X^2 = 5634, df = 2, p < 0.001).

The most important conclusion arising from these data is that the walruses are not hauling out indiscriminantly on floes. They are clearly selecting from the distribution of available floes. In August there is also evidence that they are selecting an area which contains a greater proportion of the preferred floe sizes. Although there is a significant difference when we compare the distribution of occupied floe sizes in September with that in August, the chi square value (18.2, df = 1) is much less than for the comparisons between the occupied floes and the total distribution of available floes in either of these months.

Number of animals on floes: Figure 11 shows that the distributions of the number of animals on a floe were similar in both August and September being unimodal with a peak between 1 and 15 animals per floe. These distributions were not significantly different from each other (X^2 = 1.84, df = 1).

Floe coverage by walruses: Since the distribution of the number of animals on floes was consistent when comparing September 1974 and August 1975, we next looked at the percentage cover to see if the size of the floe was limiting the number of walruses hauled out on it or if some other factor such as the social behavior of the animals was limiting the number on a given floe. In order to determine percentage cover of floes by walruses, we outlined the perimeter of each of the walrus groups on a floe and compared the areas within the outlines with the total area of the floe. We did not attempt to subtract from the percentage covered the spaces between individual animals. Thus it is possible that two groups containing the same number of animals on the same size floes could give different values for percentage cover if one group was tightly packed and the other had small spaces between the animals. However, the animals usually had approximately the same spacing so that this method of determining percentage cover did not severely bias our results.

Figure 10 . Distribution of the sizes of ice floes on which hauled-out walruses were photographed. The distributions are for September 1974 and August 1975.

Figure 11 . Distribution of the number of floes on which different numbers of walrus were hauled out. The distributions are for September 1974 and August 1975.
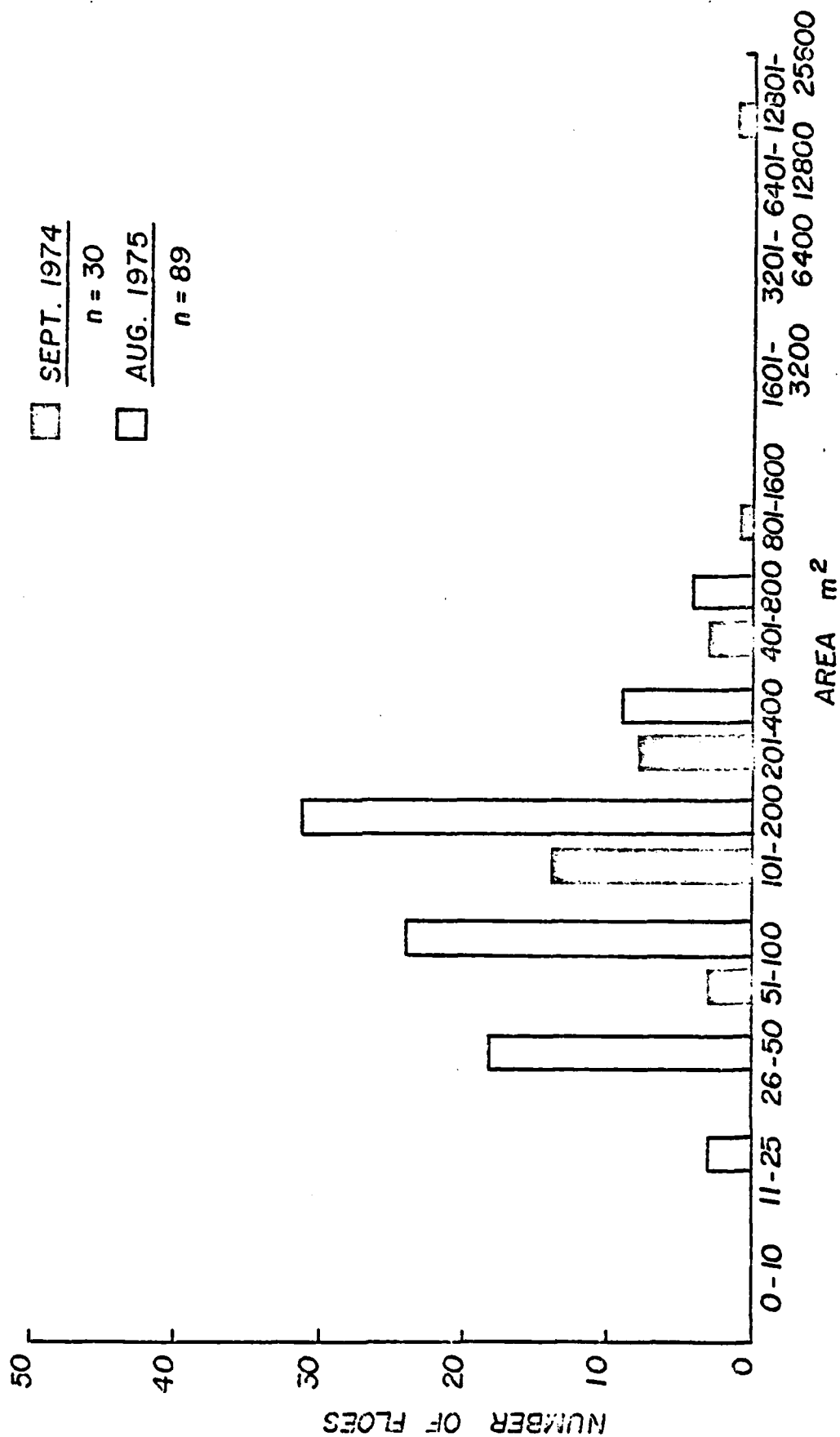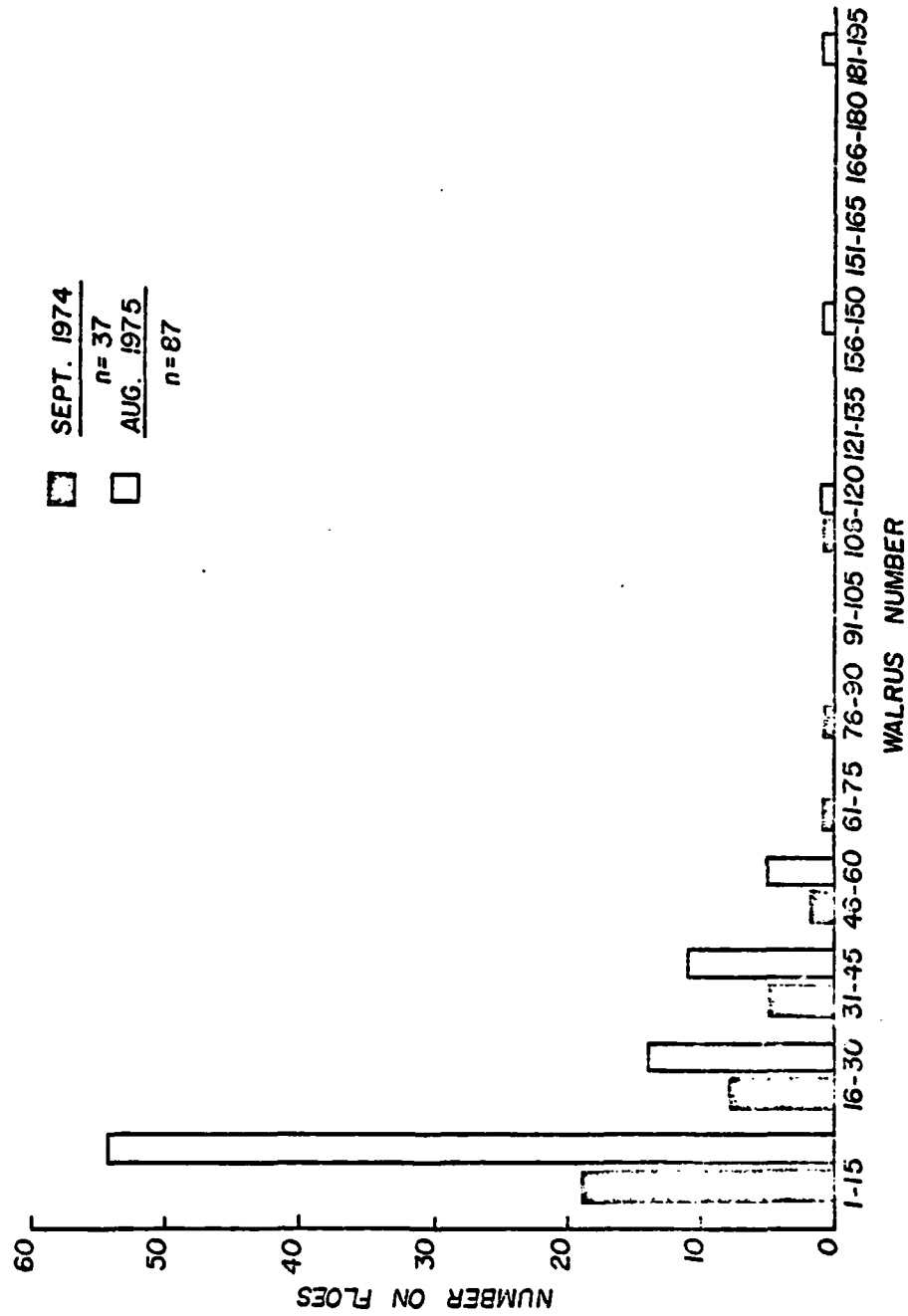
Figure 10

Figure 11

Figure 12 compares the distribution of percent cover by walruses of floes for August and September. There is a significant difference in these two distributions (X^2 = 21.45, df = 3, p < 0.001). The September distribution is sharply skewed toward a low percentage cover of the floe, whereas in August the distribution shows a relatively uniform number of floes in each percentage covered category. This analysis indicates that in the majority of cases the size of the floe is not the limiting factor determining the number of animals hauled out on it.

The preceding analysis looked at the percentage of the floe covered without regard to the size of the floe. A reasonable hypothesis would be that there would be a tendency for a greater percentage of the smaller floes to be covered. However, this was not borne out in the data presented in Figures 13 and 14. There was no correlation between the percentage covered and the size of the floe in either September or August (Kendall rank correlation tests τ = -0.0858, t_s = 0.66, n = 30 and τ = -0.0453, t_s = 0.64, n = 91 for September and August respectively).

<u>Synchrony and periodicity of hauling out</u>: All of our observations of walrus hauling-out periodicity were made during our icebreaker trip in July 1977. Figure 15 summarizes our observations of one walrus herd over a period of almost two

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Figure 12. Distribution of the floes by the percentage of the floe which was covered by hauled-out walruses. The distributions are for September 1974 and August 1975.

<u>Figure 13</u>. The relationship between the size of the floe on which hauled-out walruses were observed and the percentage of the floe covered. The data are from flights in September 1974.

<u>Figure 14</u>. The relationship between the size of the floe on which hauled-out walruses were observed and the percentage of the floe covered. The data are from flights in August 1975.

<u>Figure 15</u>. Patterns of walrus hauling out during two weeks in July 1977. The numbers of animals hauled out are shown over four periods of walrus hauling out. The helicopter search flights of about 1.5 hr duration are indicated as f-3 through f-12. We were unable to search for the animals or observe them during periods where fog is indicated. The locations of the hauled-out groups are indicated. The dashed lines indicate that we are uncertain just how many animals were left on the ice at a given time.

    <u>Note 1</u>: This very large group left the ice without disturbance sometime before flight 5.
    <u>Note 2</u>. There were initially four groups--250 animals located 17 km from the ship, 500 animals at 21.3 km from the ship, 200 animals at 26 km from the ship, and 250 animals at 32.4 km from the ship.
    <u>Note 3</u>. The first group was driven into the water at this time due to our radio-tagging attempts.
    <u>Note 4</u>. The second group went into the water at this time in response to a polar bear.
    <u>Note 5</u>. The third group left the ice. We know of no disturbance.

Figure 15. (Notes continued)

Note 6. Most of the animals from the first three groups regrouped at the site of the fourth group.

Note 7. All the animals were driven into the water at this time as the ship drifted through their haulout area.

Note 8. On this flight we located several groups totalling about 100 animals 1.9 km from the ship and another concentration of several groups totalling 536 animals (based on later on-ice counts) at 23.2 km from the ship.

Note 9. By this time all groups in the first concentration were driven into the water by our radio-tagging attempts.

Note 10. By this time many of the groups of the second concentration had gone into the water in response to tagging attempts, behavioral observations, and the approach of a polar bear.

Note 11. Twelve groups were still visible from the ship.

Note 12. All the remaining groups had left the ice. We know of no disturbance.

Note 13. One group located 12 km from the ship increased in size from 75 on flight 11 to 250 on flight 12. We also located a second concentration of 500 animals in 7 groups located 22.2 km from the ship.

Note 14. All of the groups gradually went in the water in response to our on-ice activities of behavioral observations, thermal data recording and photography.

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weeks along the ice edge in the Chukchi Sea. Except for the first time we located the animals on 14 July when we found 1000 animals in one large group, the walruses were hauled out in several groups. The total estimated number hauled out at any one time varied from about 650 on the 19th to about 1200 on the 17th. Since we usually tried to keep the helicopters well away from the animals so as not to disturb them, our counts are not as accurate as they would have been had we approached the animals more closely. If we take the maximum count of 1200 animals to be a reasonable estimate of the total number in the area, then we can say that any time we spotted walruses hauled out, the majority of the herd would also be hauled out somewhere in the general area.

Again, it is important to note that none of these animals was marked or radio tagged to identify individuals. Hence, we do not know for certain that we were always observing the same walruses. However, this is the most likely explanation since we searched 80 km along the ice front on most of the helicopter flights and found only this concentration of animals.

On the 17th we observed four groups along the ice front with 4.3, 4.7 and 6.4 km spacing between groups. On the 20th, there were many groups in two concentrations 21.3 km apart and on the 25th there were again two concentrations 10.2 km apart. The latter concentration consisted of seven groups. The conclusion is that indeed there was a high degree of synchrony of hauling out in this walrus herd even though the individual groups were separated by as much as 21.3 km. The question of whether this synchrony was triggered by environmental cues, intrinsic rhythms, or communication cannot yet be answered. Underwater sound recordings revealed only low levels of underwater vocalizations by these animals. There was insufficient change in environmental conditions to explain the periodicity of hauling out. Air temperature ranged from 3.3 to 6.2° C and the blackbody
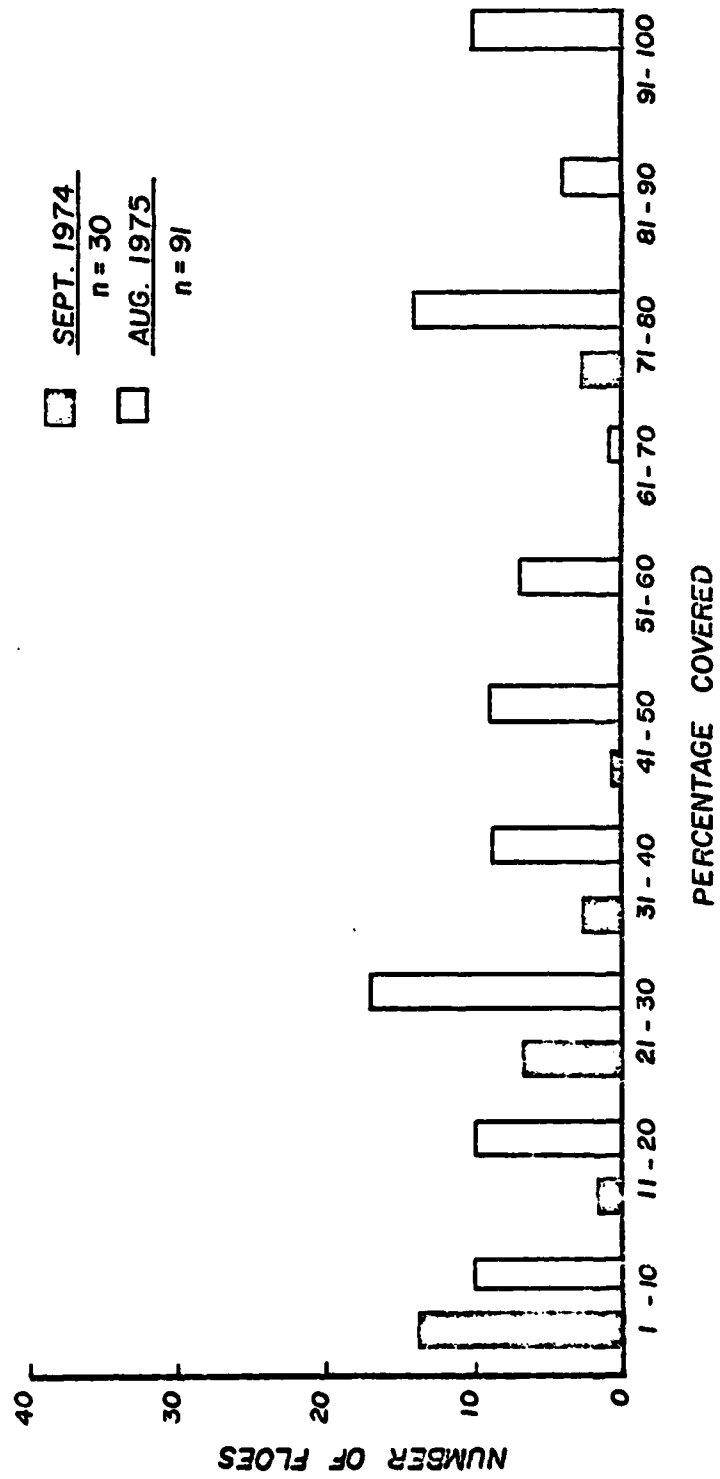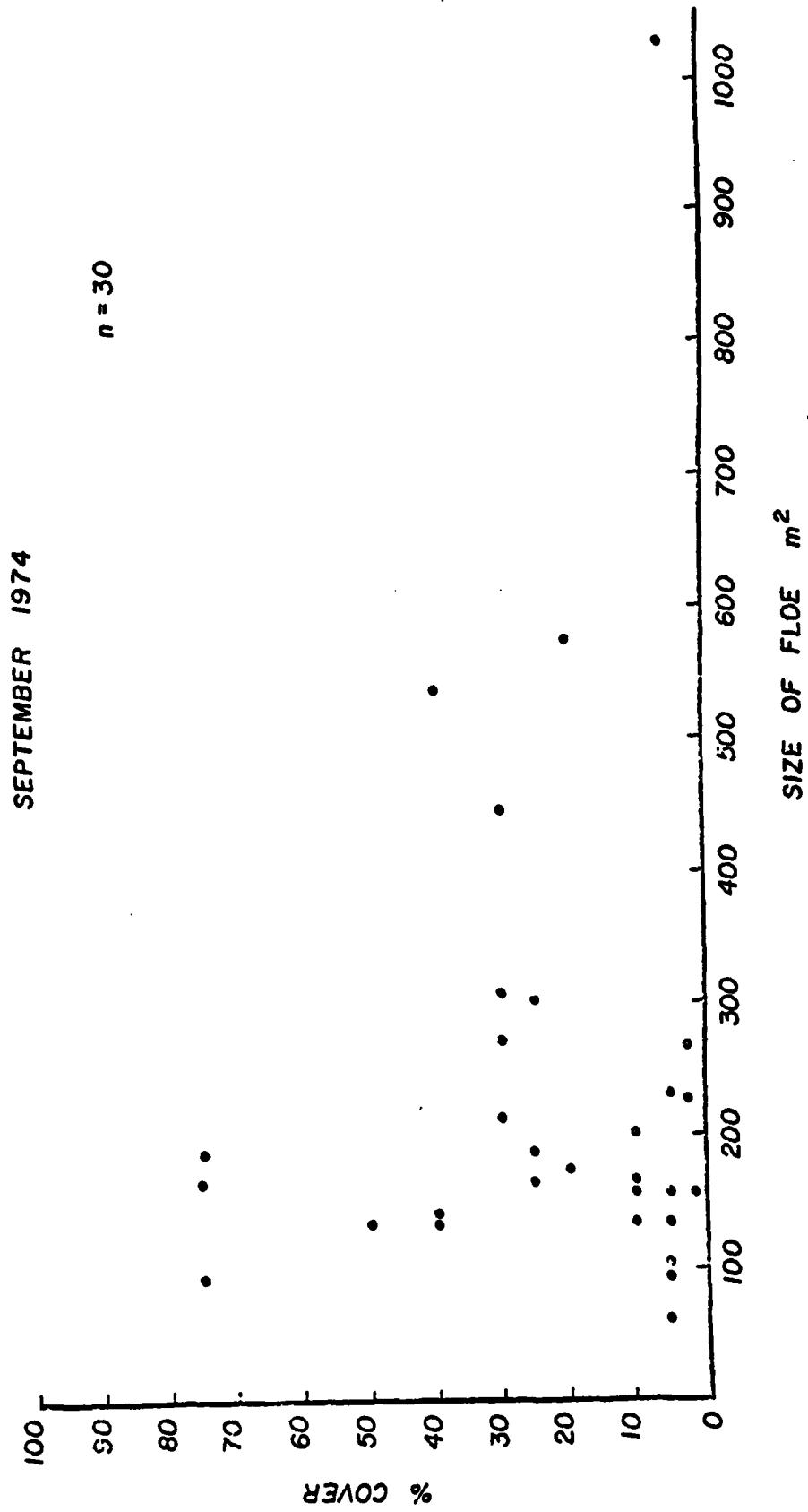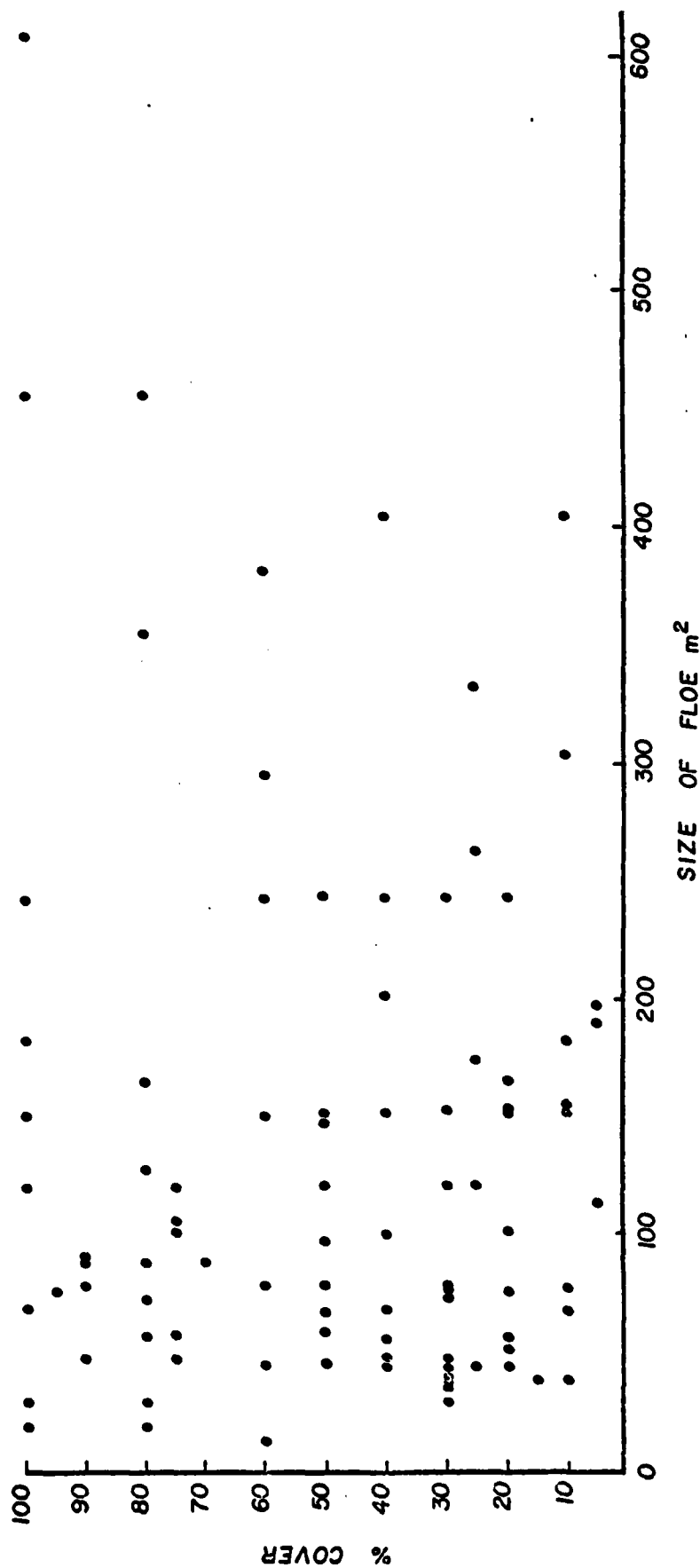
PERCENTAGE COVERED

Figure 12

SEPTEMBER 1974

n = 30

SIZE OF FLOE m²

% COVER

Figure 13

36

AUGUST 1975   n = 91

SIZE OF FLOE m²

% COVER

Figure 14

fog

26th

Note 14

35hr

25th

$71^\circ55'$ N $164^\circ07'$ W

E-12

E-11 Note 13

24th

fog

E-10

E-9 fog

23rd

74hr

fog

22nd

Note 12

21st

Note 11

Note 10

46hr

20th

$71^\circ29'$ N $165^\circ50'$ W

Note 9

Note 8

E-8

19th

Dates in July 1977

Figure 15

33hr

fog

18th

Note 7

Note 6

39hr

17th

$71^\circ21'$ N $165^\circ54'$ W

Note 5

Note 4

Note 3

E-7

16th

Note 2

24hr

E-6

E-5

15th

Note 1

$71^\circ12'$ N $165^\circ35'$ W

E-4

E-3

14th

1500
1400
1300
1200
1100
1000
900
800
700
600
500
400
300
200
100
0

Estimated number of walrus hauled out

temperature varied between 3.9 and 16.0° C. The highest wind speed 2 m off the ice was 5.8 m/sec and the lowest recorded 10 cm off the ice was .2 m/sec. Relative humidity varied from 78 to 92%. The infrared surface temperatures of dry walrus ranged from 20 to 30° C.

Since the animals apparently exhibited such a high degree of synchrony, the periodicity should also be readily apparent. The hauled-out phase appears to be regular with a mean duration of 40 ± 6 hours for the three periods the animals were hauled out after we located the herd. We have not included the first period since no searches had been conducted in the area prior to the time we spotted the large herd hauled out. We have no way of knowing how long these animals might have been hauled out prior to our discovery of them.

The question naturally arises as to what extent the haulout times measured were shortened by disturbances caused by the ship and our on-ice activities. Two of the three periods we measured terminated with some animals of the herd leaving the ice because of disturbance. Some returned shortly, however. These two haulout times were recorded as 39 and 35 hours. The animals left the ice without being disturbed by us at the end of one 46 hour period. Quite possibly our activities shortened the haulout period somewhat, but we have evidence from flights and on-ice observations that when the animals were early in their hauling-out period, they were not easily deterred from hauling out. For example, 75 animals observed hauled out on flight 11 went into the water in response to the helicopter. However, on flight 12 about 6 hours later, a total of 250 animals were hauled out again at this very site. Thus, we believe that our activities did not significantly shorten the time the animals were hauled out.

In contrast to the relatively small variation for the haulout periods, the inter-haulout intervals showed quite a bit of variation with a mean of 44 ± 27 hours. The inter-haulout intervals when the animals did not shift their position more than 5.6 km relative to the ice were 24 and 33 hours. However, when they moved 24 km relative to the ice, the interval was 74 hours.

To see if there were any particular times of the day when the animals were more likely to be hauled out, the day was broken into three hour intervals. Table IV gives the number of times in any given three hour interval that 50 or more walruses were observed hauled out. There is no evidence that there is any particular time of the day when the walruses are more likely to be observed hauled out ($X^2 = 0.829$, df = 7, N.S.).

DISCUSSION

This study demonstrates the value of remote sensing technology for increasing our knowledge about the natural history of walruses, and specifically about their hauling-out behavior. This understanding is particularly enhanced through the complementary results obtained by both visual photography and infrared imagery. There is synergism between use of the two technologies, in which the detection capabilities of the infrared scanner and the resolution of visual photography provide information on the presence and numbers of animals.

TABLE IV

Walrus hauling out and time of day in July 1977

Time Interval	Number of times 50 or more walrus were observed hauled out during interval
0000 - 0300	5
0300 - 0600	5
0600 - 0900	5
0900 - 1200	6
1200 - 1500	6
1500 - 1800	7
1800 - 2100	7
2100 - 0000	6

While emphasizing the advantages of the multi-spectral concept in walrus studies, we also emphasize the value of real-time, trained marine mammal observers on any remote sensing flight. Not only is the field of view of a human observer much greater than that of any remote sensing instrument, but an observer is often able to detect animals which are leaving the ice in advance of the aircraft's arrival over the site.

It is difficult to compare the cost-effectiveness of flights in this experiment with other walrus survey flights. For one thing our goals were different. We were primarily interested in natural history data which could be used to improve future aerial surveys. As Estes and Gilbert (1978) have convincingly demonstrated, until our knowledge of walrus natural history is significantly improved, traditional aerial surveys will not produce meaningful population estimates. We feel that much of the data we have presented in this report could not have been obtained without the use of remote-sensing technologies. We further recognize though that our contribution to walrus natural history does not provide sufficient information to redesign aerial census flights. We had too few flights to accumulate the necessary data base to reach that goal.

Although we conducted our remote-sensing flights primarily in a four-engine jet aircraft with redundancy in most systems, one could probably achieve comparable results in much smaller aircraft capable of carrying a 228.6 mm camera and an infrared scanner and at least one trained observer. The continued expansion of our knowledge about walrus hauling-out behavior would more than justify the additional cost to incorporate these remote sensing technologies on future flights.

We now have evidence for moderate site tenacity of the walrus to ice in its hauling-out behavior at two times of the year: the late winter and the late summer. Over a period of several days at least, walruses tended to haul out on the same general ice area even though individual floes shifted relative to each other and the sea ice shifted its geographical position. At other times of the year, for example, during migration in May, the animals are continually moving with respect to geographical location. During the period of time we have observed walruses moving with the ice, but maintaining their position relative to the ice, the ice had not moved a great distance. The maximum amount of ice movement we have seen when the walruses maintained their relative position was 22 km over a period of two days. Movements of this magnitude probably would not introduce serious errors into population estimates obtained from intensive set-grid surveys requiring several days to complete. However, we do know that the ice on which the animals are hauled out can move up to 45 km in a day during the late winter (W. Campbell, pers. comm.). Movement of animals of this magnitude over a period of a few days could displace a walrus concentration sufficiently so that on multi-day, fixed-grid flights the animals could be either double counted or missed entirely. The calculations required to predict the movements of ice over short time periods are straightforward and should be included in future surveys in order to determine appropriate changes in the flight grid lines from one day to the next. Such adjustments have not been included in past surveys, thus introducing the possibility of significant error.

Burns et al. (1976) presented a regional classification of ice type relative to marine mammals. We attempted to build upon this overview with detailed

studies of local features of the ice which might correlate with the presence
of hauled-out walruses. For winter ice in April 1976 we were able to obtain
a good discrimination between three types of areas: those containing less
than 2%, 2 to 10% and greater than 10% of the observed hauled-out walruses. The
discriminant variables in this analysis were four categories of ice based on its
thickness. When the discriminant functions obtained using the April 1976 data
were applied to the April 1975 data they were not effective in correctly classi-
fying the quadrats from the April 1975 survey according to what proportion of
the observed hauled-out walruses they should contain. Indeed the discriminant
functions based on the April 1975 data were also unsuccessful in correctly classi-
fying the quadrats from the April 1975 survey. This result could arise if there
was a surplus of suitable ice available and all of it could not be occupied by
the numbers of walrus in the area. In order to evaluate this possibility, data
from additional years must be obtained. Thus, although we have made some progress
toward objectively identifying "walrus ice," we are not yet at the stage where
we can use local characteristics of the ice to predict from one year to the next
where walruses in the area are likely to haul out.

Our results for the late summer, in August and September, show that at this
time of the year walruses appear to prefer floes which range from 100 to 200 m^2
in area. The animals make these choices independently of the distribution of
floes available within at least 2 km of their hauling-out location along the ice
edge. We do not have sufficient data from regions farther removed from hauled-
out walruses to know whether they are specifically avoiding areas which lack
sufficient representation of the 100 to 200 m^2 floe size class. There are, of
course, other factors, such as food availability, which determine the animals'
presence. Maps identifying the areas of walrus food concentration are becoming
available (Fay, et al., 1977; Stoker, 1978). Theoretically, we could compare
information on food availability with distribution of preferred floe size in
order to identify with a high probability areas where walruses should be found
hauled out in the late summer. Unfortunately, the size of floes that are
preferred are too far below the resolution threshold of current satellite remote
sensing instruments for that technology to be valuable in the near future. Until
we have higher-resolution satellite imagery, our present knowledge of walrus
floe size preference in late summer cannot be incorporated into operational
models using satellite data in order to stratify survey flight effort.

As has been observed by Estes and Gilbert (1978), we found that the dis-
tribution of group sizes of walruses in both late summer and late winter could
be fit with a truncated negative binomial distribution. This distribution of
walrus group sizes seems to be one aspect of walrus hauling-out behavior which
is invariant from one season to the next. In the late winter, the group size
class of single animals is underrepresented compared to the predictions of the
truncated negative binomial distribution. This is not surprising because of
the increased thermoregulatory costs of hauling out for individual animals at
that time of the year. However, in the late summer when environmental condi-
tions usually allow a hauled-out walrus to be in its thermoneutral zone, the
size class of single individuals approaches that predicted by the truncated
negative binomial distribution.

The "aggregation parameter," 1/k, was consistently larger for walrus groups
in the late winter compared to the late summer. This might indicate that in

the late summer the natural aggregation tendencies of walruses are somewhat inhibited by having to haulout on dispersed and generally smaller floes, although the percentage covered results show that often there was additional space available on an occupied floe. An alternative interpretation is that walruses aggregate more in the late winter than the late summer because of the thermodynamic advantages of large herds. Both of these interpretations must be considered tentative in light of the current arguments against the use of the negative binomial as a model for aggregation (Taylor, et al., 1979).

One task of this contract was to develop a model of walrus hauling-out behavior that can be incorporated into assessment programs. Although our remote sensing flights have provided us with an extensive amount of data in a format which allowed detailed analysis, we are still not at the point where a detailed model would provide information which could be incorporated into assessment programs with any degree of confidence. Therefore, rather than formalize our ignorance in mathematics, we will summarize where this study has lead us on the road to a predictive model and suggest where we think future efforts should focus.

The major components in such a model will be those dealing with the microclimate of the animals, the patterns of activity, and social behavior, particularly as these influence synchrony and periodicity of hauling out.

We feel that available remote sensing technology cannot measure the microclimate of che walrus. Therefore, we suggest that this component of the model be tied to a parameter which can be remotely sensed: the surface temperature of hauled-out walruses. The assumption is that walruses will haul out primarily when the ambient conditions are such that they can be in their thermoneutral zone. Ray and Fay (1968) place the thermoneutral zone of walruses within the range of body surface temperatures to be between 20 and 32° C. Additional studies will probably show that the thermoneutral zone can be extended to low skin temperatures.

Further field work on walrus energetics should attempt to correlate walrus surface temperatures to microclimatological variables which place the walrus within its "climate space" (Porter and Gates, 1969). As data accumulate, a regression of $\log(F - 1)$ with T_s should be attempted. F is the fraction of a known size herd hauled out and T_s is the surface temperature of the hauled-out animals. If the regression is linear with a regression coefficient b, then $F(T_s) = 1 - \exp(-bT_s)$. This is intuitively a reasonable form for the function relating the fraction of a population hauled out and the surface temperature of the hauled-out animals.

Our current information on daily activity patterns comes from Fay and Ray (1968). A Fourier transform can be generated from their data. However, their data are based only on the relative percent of the animals that were active or hauled out; they could not be certain that all the animals in the water were observed. Also although their model fits the observations for late winter, we present evidence in this paper that there are not similar circadian activity cycles in the late summer.

We will not make a great deal of progress in better defining the activity

pattern component of the model until successful radio tracking studies have been completed. If enough animals are radio tagged, then their seasonal and weather-associated activity cycles can be extrapolated to the rest of the population.

We have provided some evidence for synchrony and periodicity in walrus hauling out in late summer. Even though we followed what we think was one population over a period of about two weeks, our estimates of the time in the water and time hauled out are first order approximations at best because of the small sample size. Several additional studies like the one we did in which we followed one walrus herd over an extended time will be required in order to accumulate the data needed for this component of the model. Again, radio tracking must be combined with these studies in order to increase the confidence that indeed the same walrus population is being observed over an extended period of time.

In conclusion, extensive remote sensing and radio tracking studies are still required before a reliable model of walrus hauling-out behavior can be constructed and used with confidence. Attempts to census walrus will remain inadequate until this is done for walrus and the other marine mammal species.

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